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(54) Abstract Title

Telemetry system in which data signals are modulated on power signals

(57) A telemetry system is capable of transmitting both power and data signals between a master unit 10 and at least one slave unit 50 (a,b) over a transmission system 12 which is part of a borehole, an oil well or a pipeline which may be a subsea installation. The transmission system comprises a tubing string or pipeline incorporating electrically isolating collars 200 a,b. A well casing or another pipeline may provide an earth/return path, the slave unit 50 being coupled between the tubing string and the well casing or between the two pipelines. The master unit 10 may use pulse width modulation of a power signal from driver 24 to send data to the slave unit 50. Power signals received by the slave unit are fed to regulators 56,58 to provide a local power supply for the slave unit. Data signals from the slave unit may be encoded by frequency shift keying at generator 64, synchronised with the pulses of the power signal, for transmission to the master unit. Data signals sent from the master unit may be detected by a timer circuit 70 and used to control valves, actuators or motors, while the data signals from the slave unit may represent the outputs of sensors. The data signals may be encrypted, e.g. using a Hamming code.

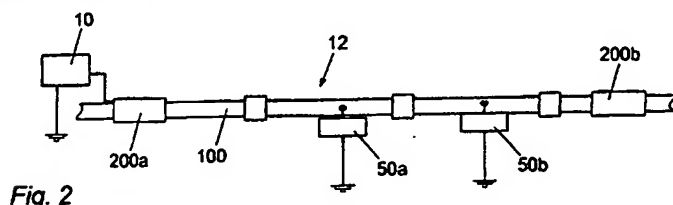
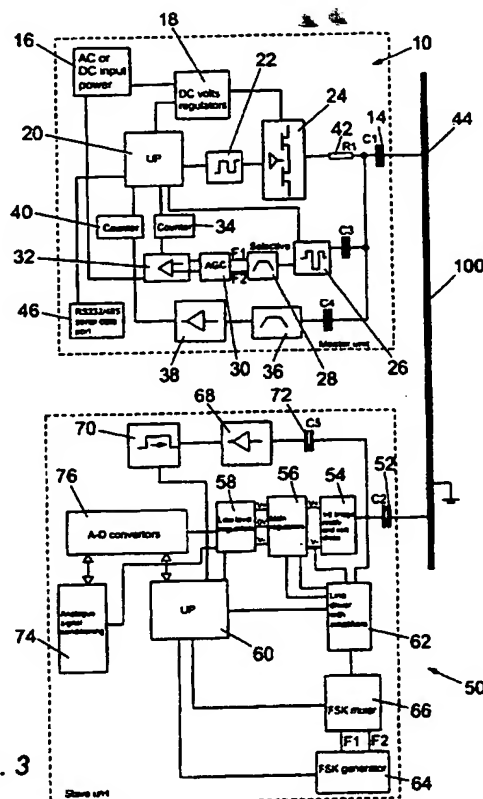


Fig. 2



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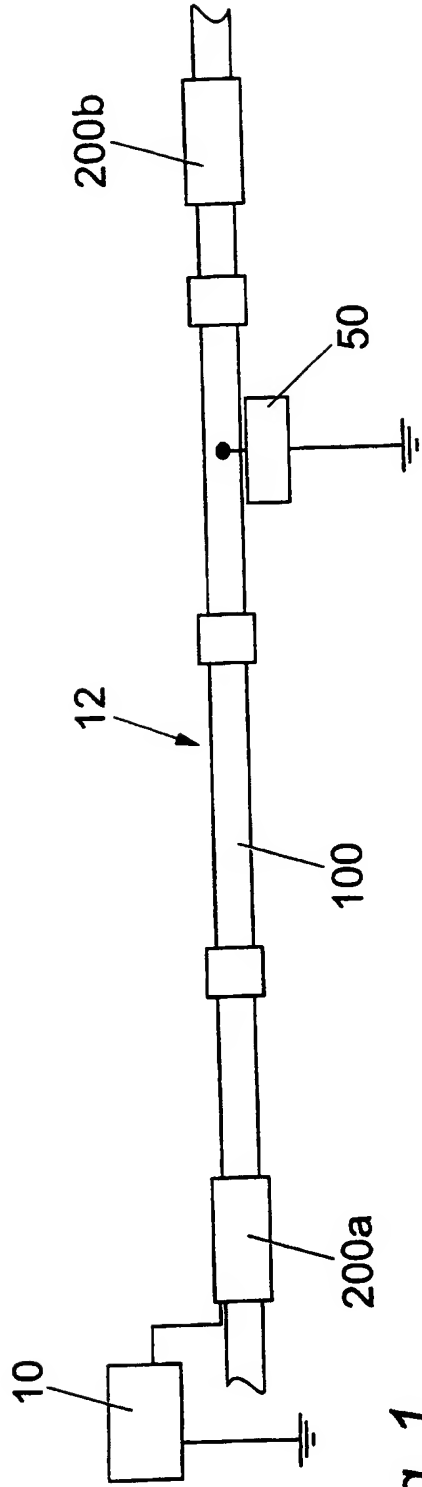


Fig. 1

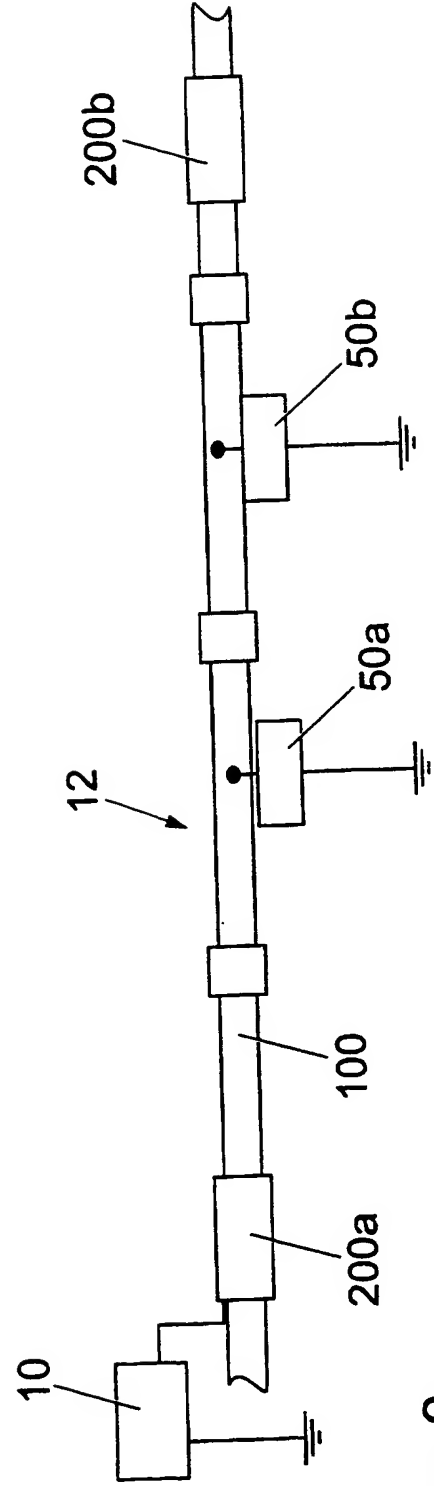


Fig. 2

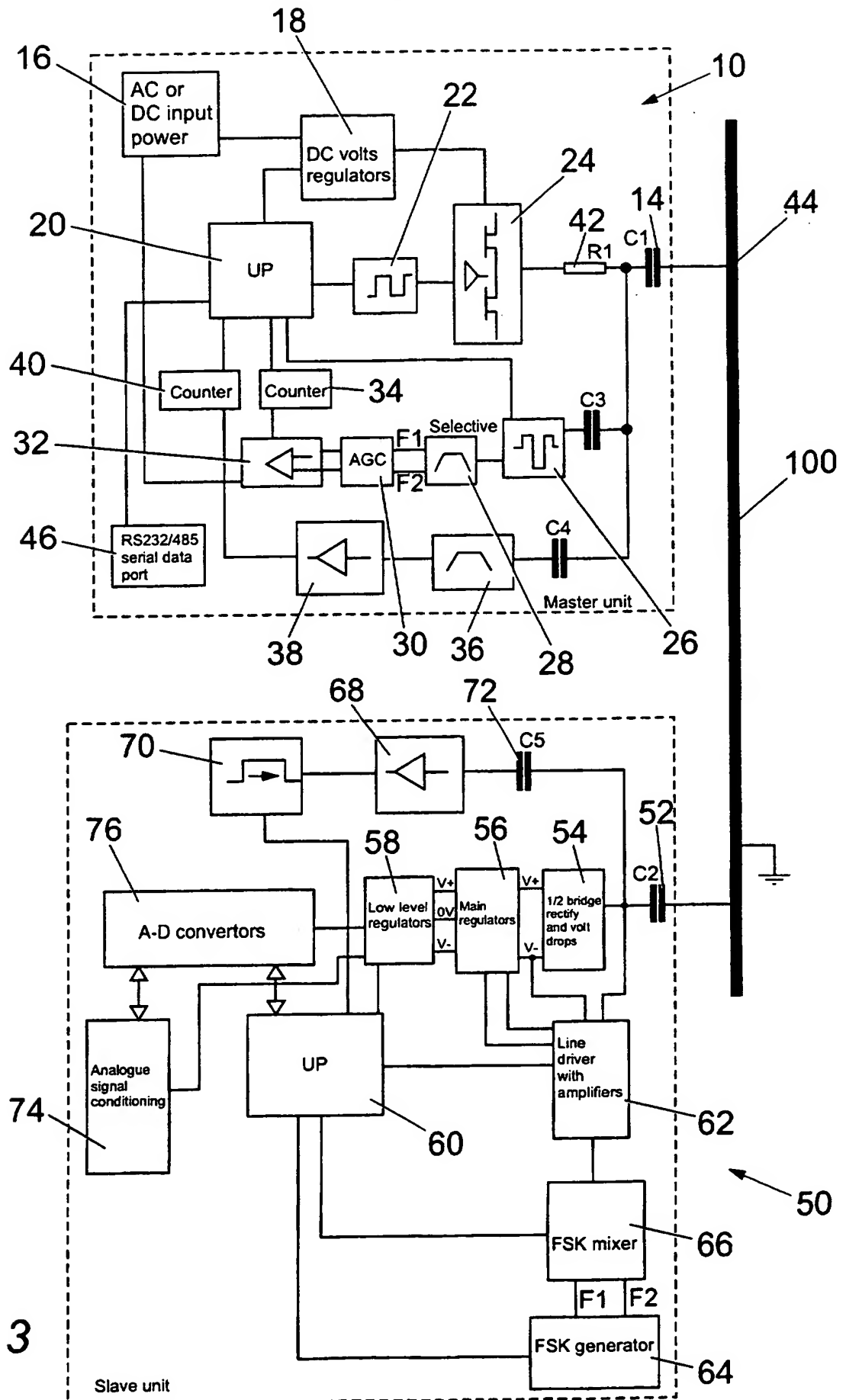


Fig. 3

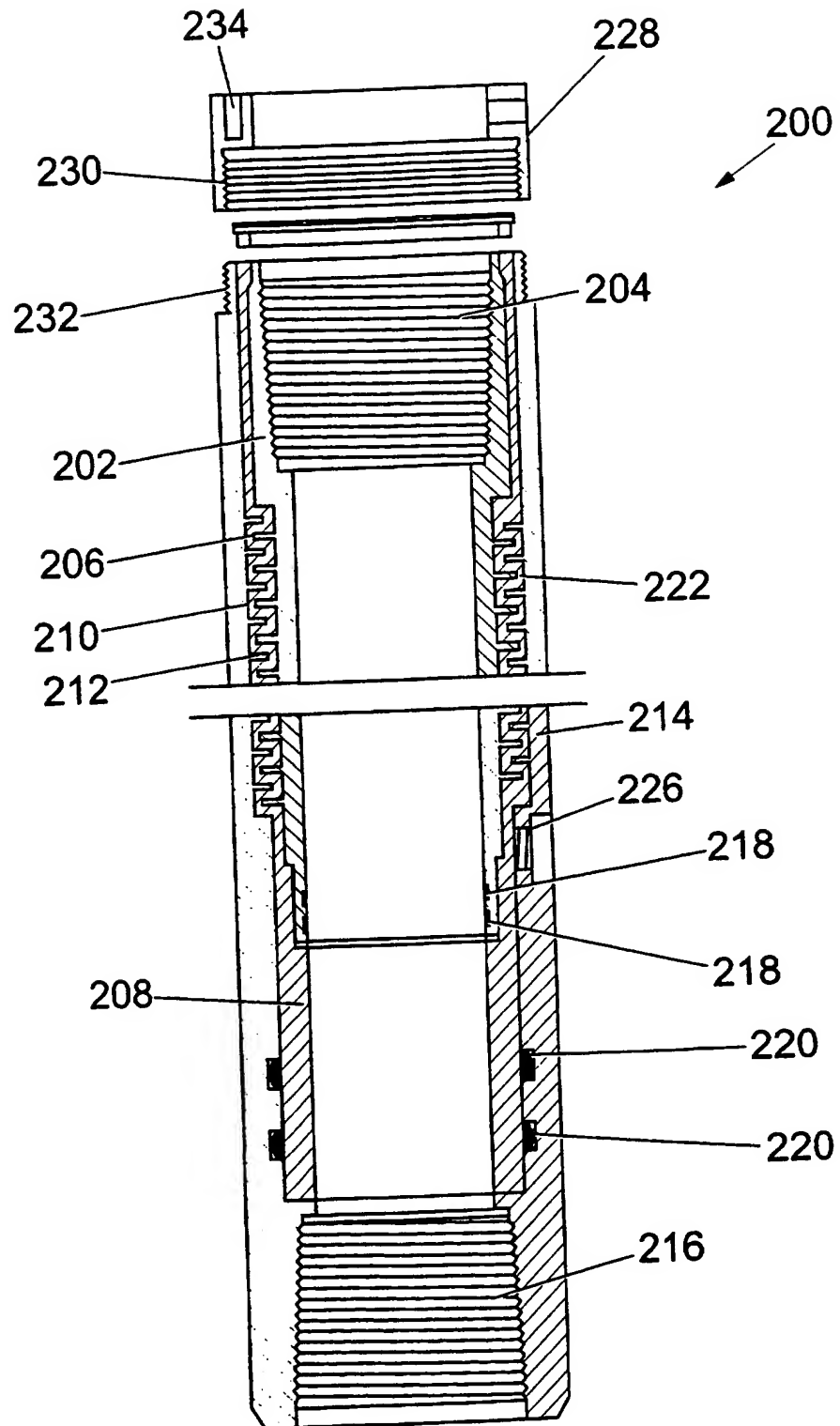


Fig. 4

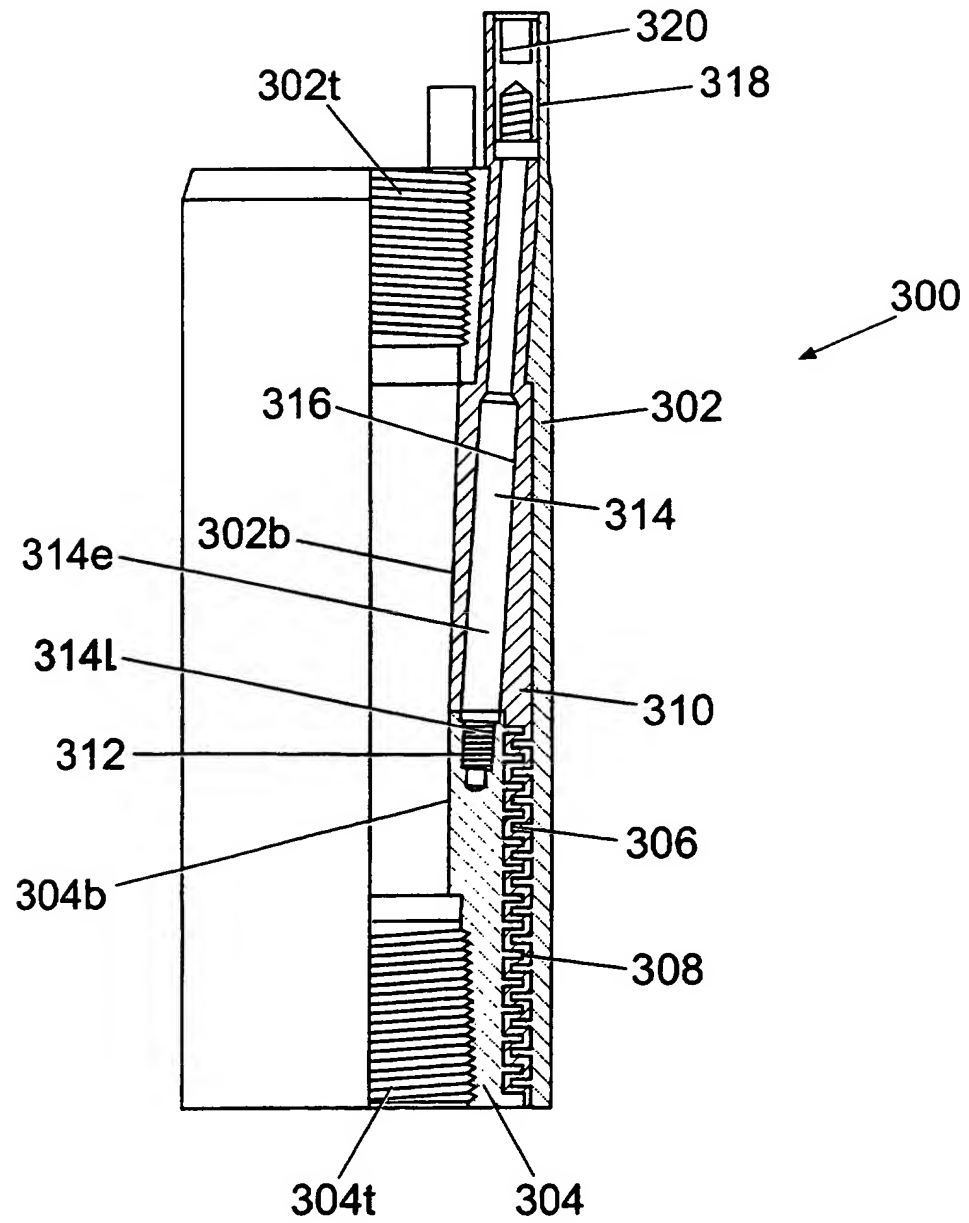
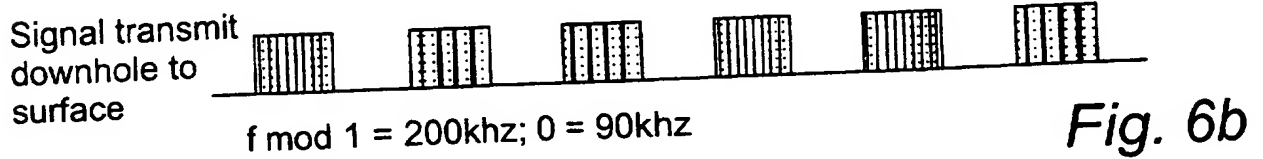
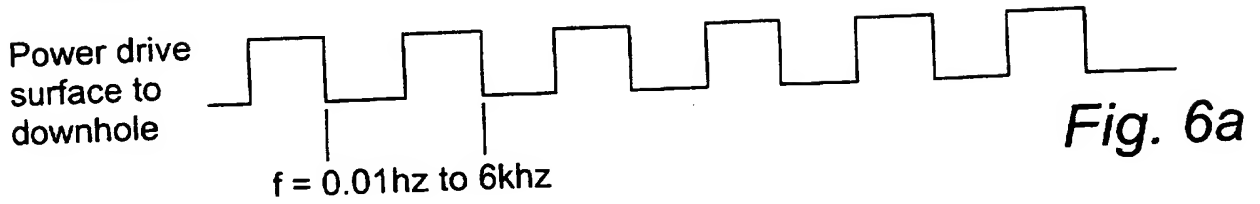
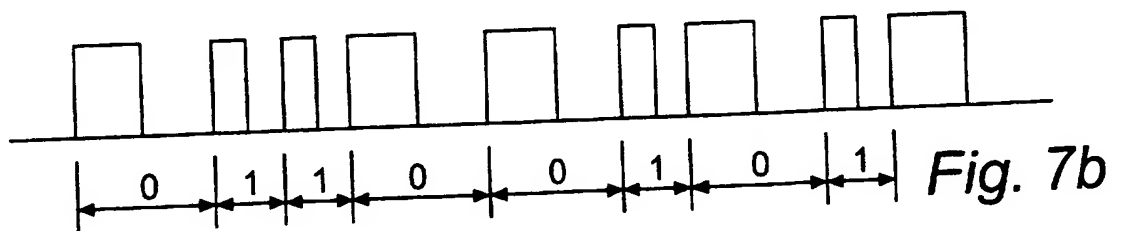
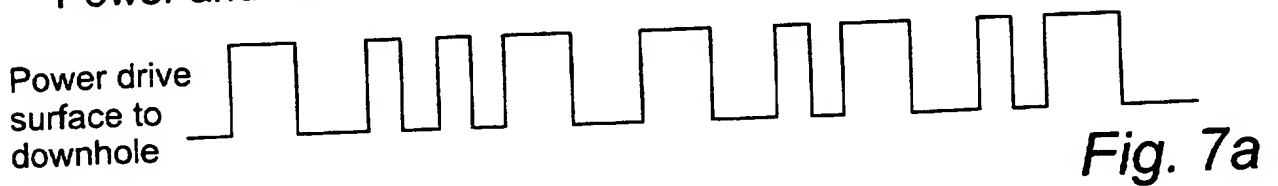


Fig. 5

Power and communications



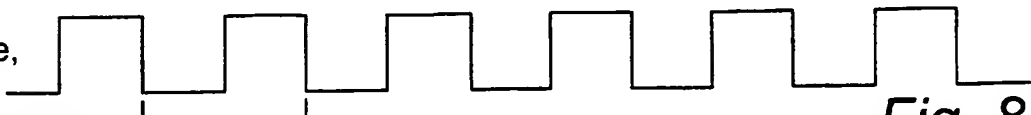
Power and communications surface to downhole



Transmission
medium
basic operating
frequency

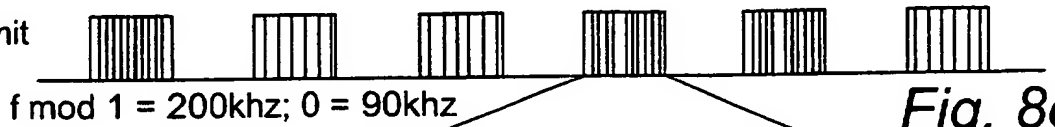
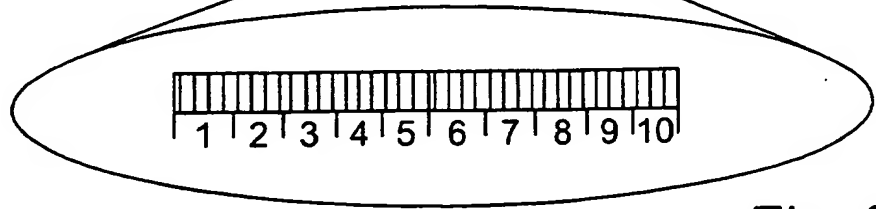
*Fig. 8a*

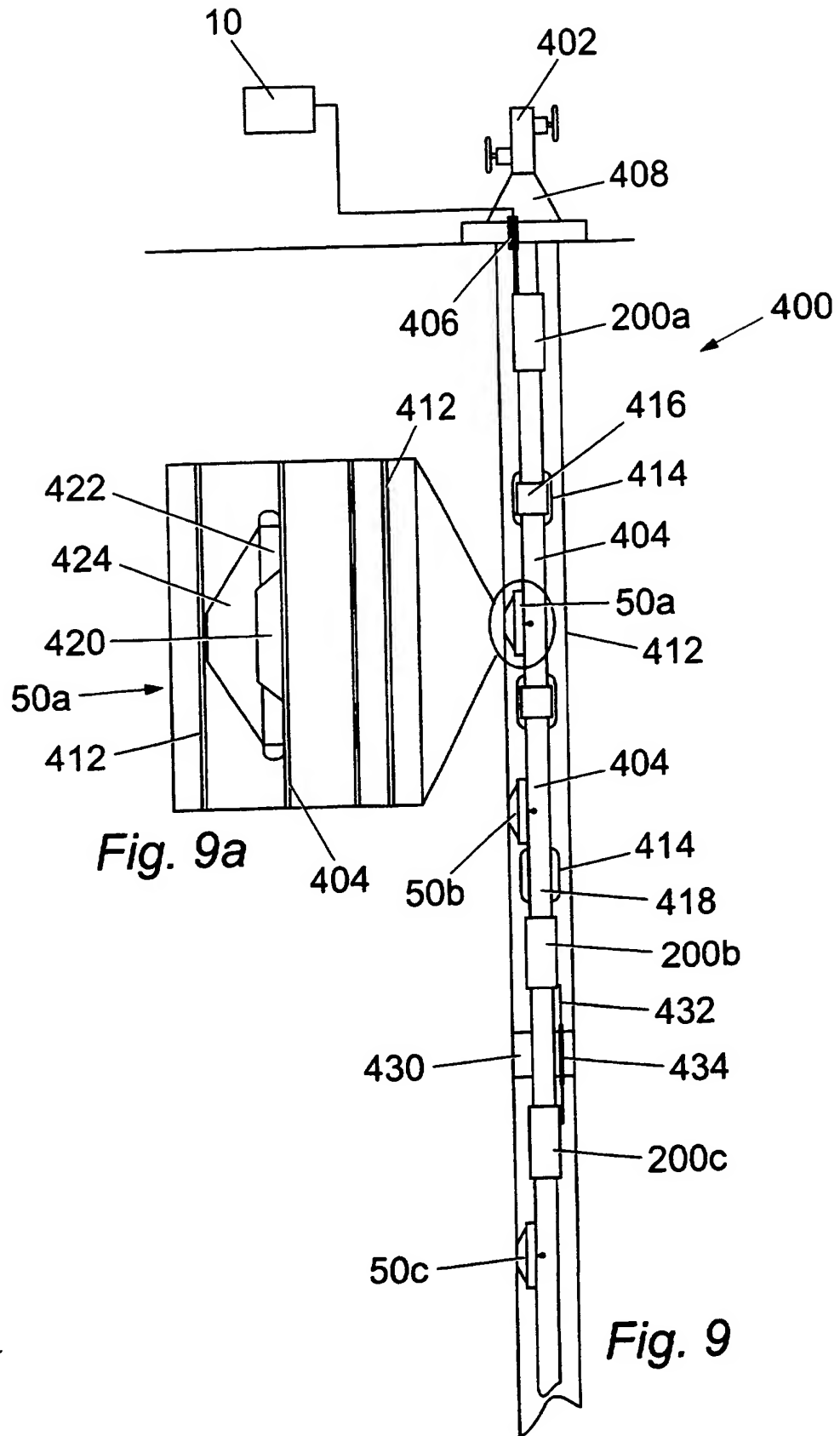
Power drive
master to slave,
synchronised
to system frequency

*Fig. 8b*

$f = 400 \text{ to } 6\text{kHz}$

Signal transmit
node to
slave

*Fig. 8c**Fig. 8d*



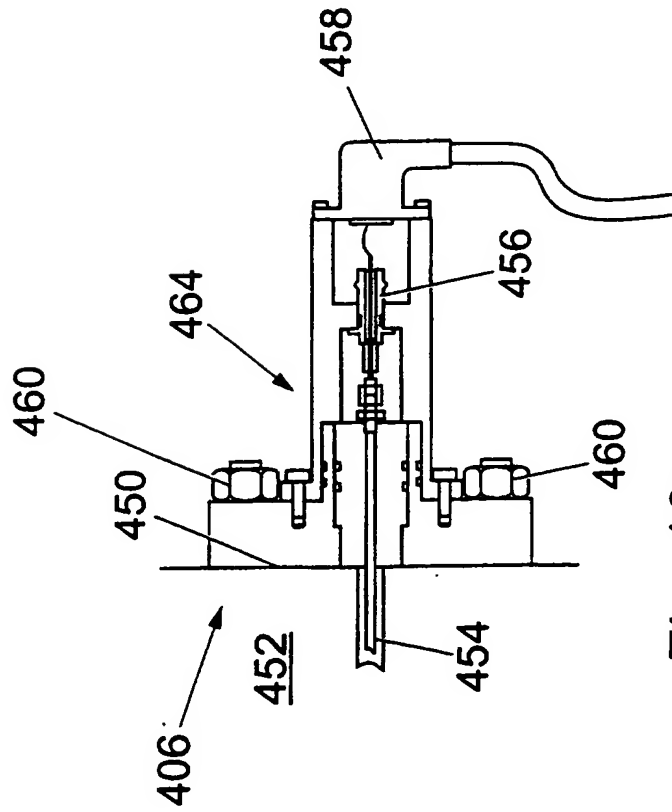


Fig. 10a

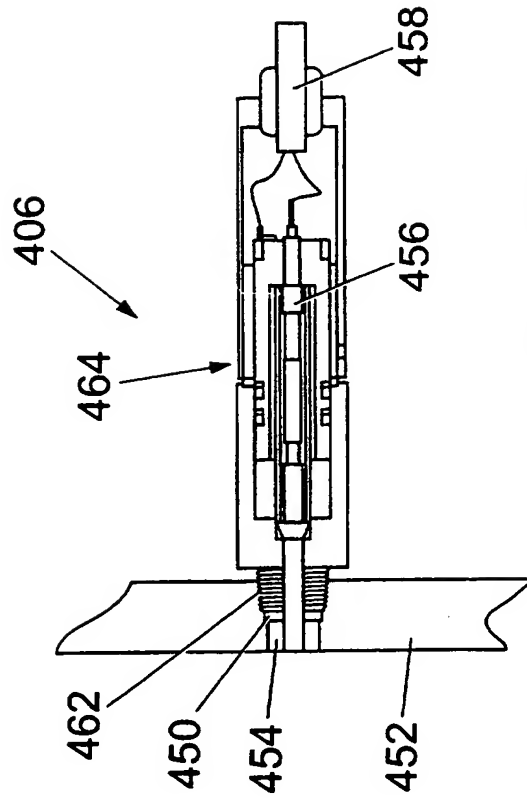


Fig. 10b

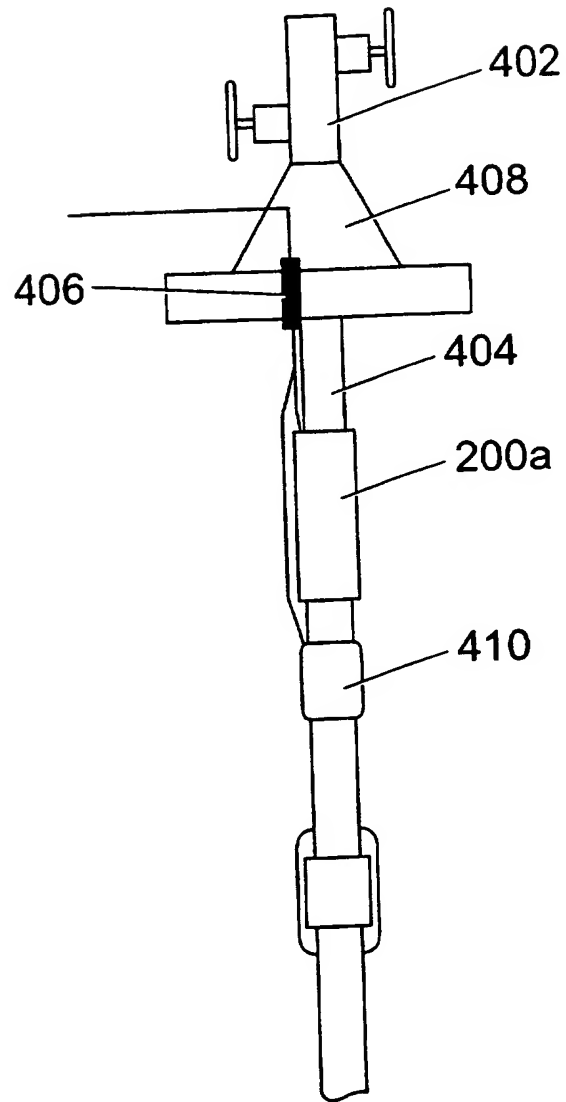


Fig. 11

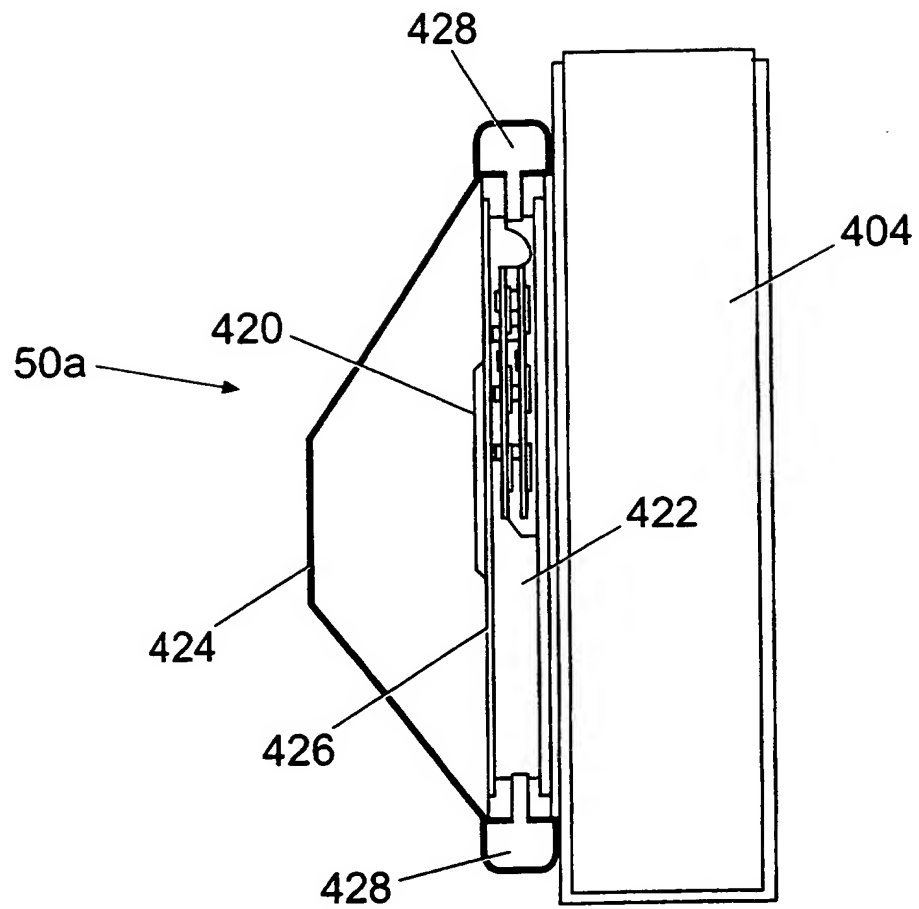
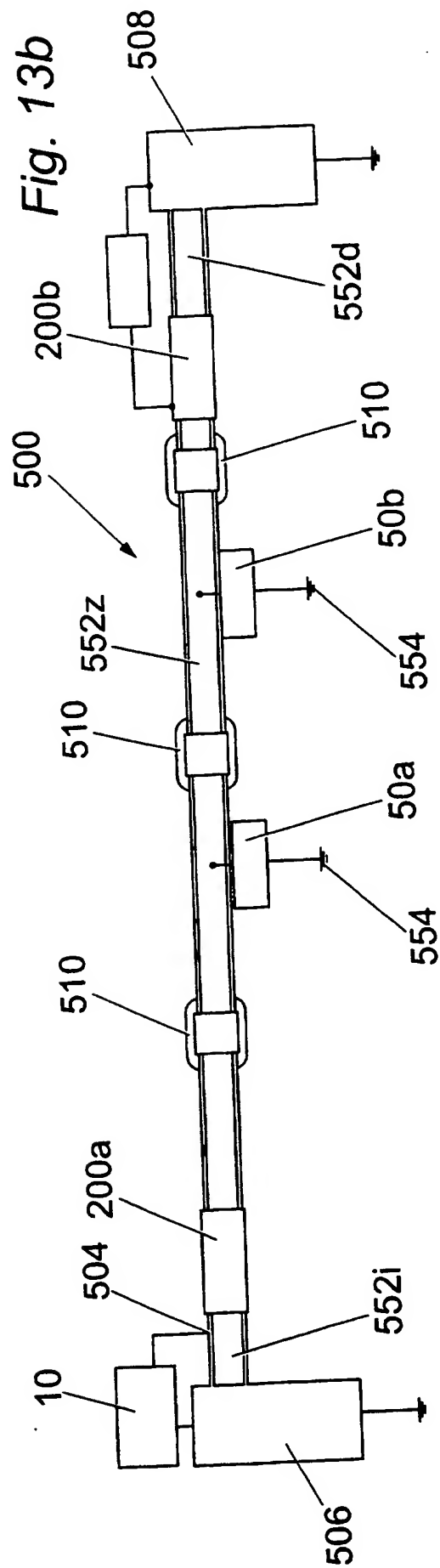
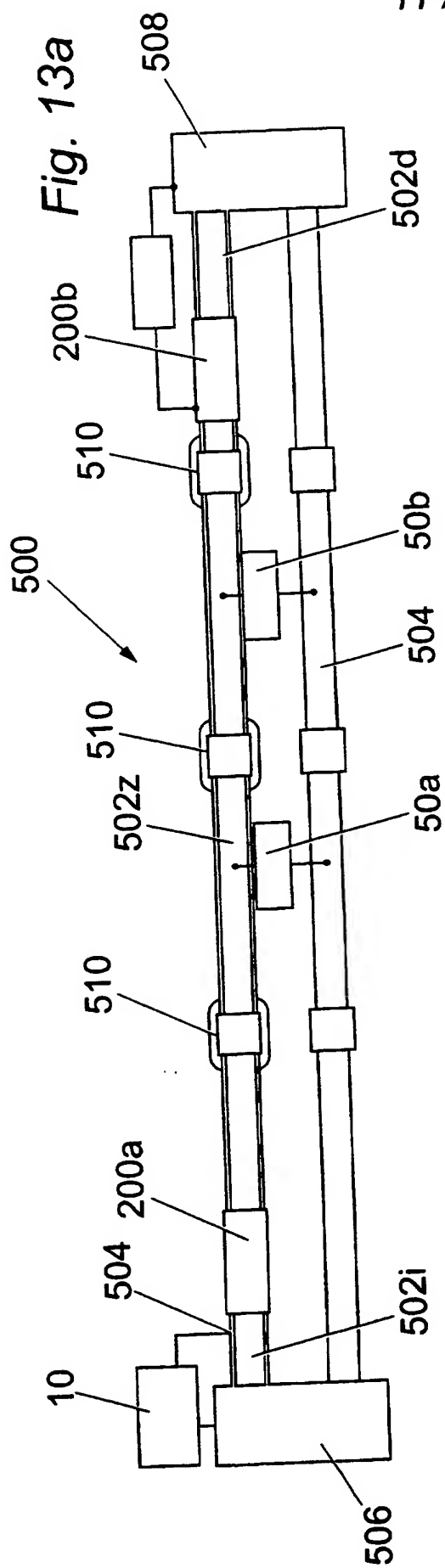


Fig.12



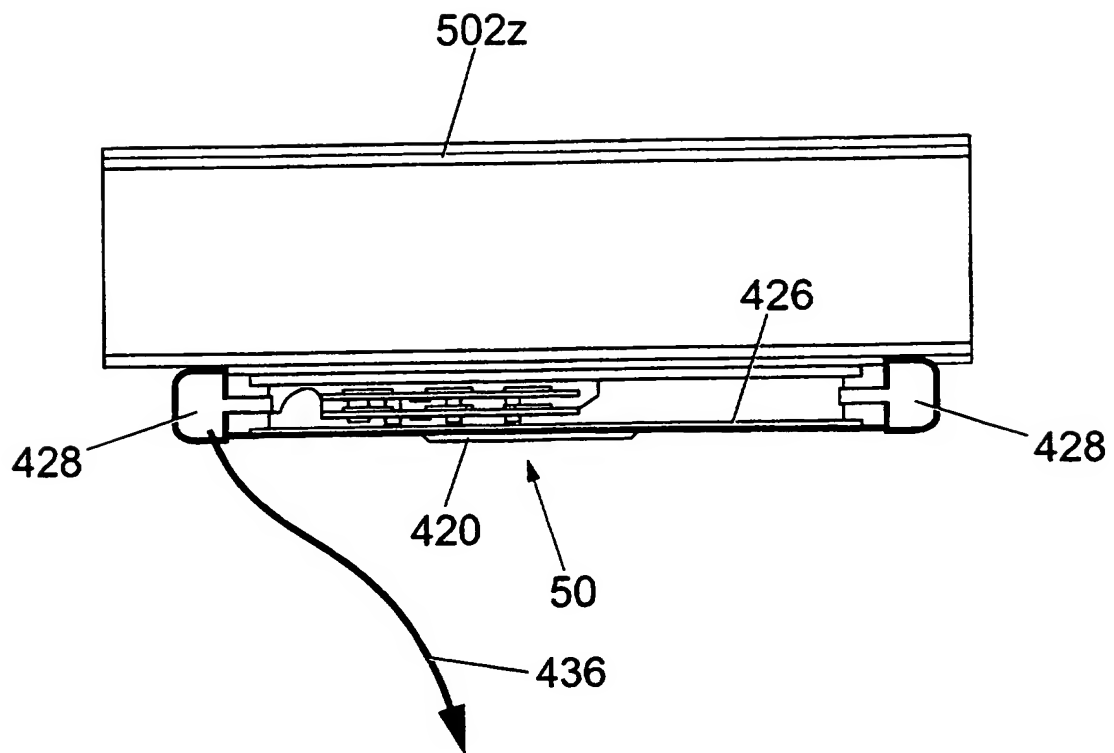
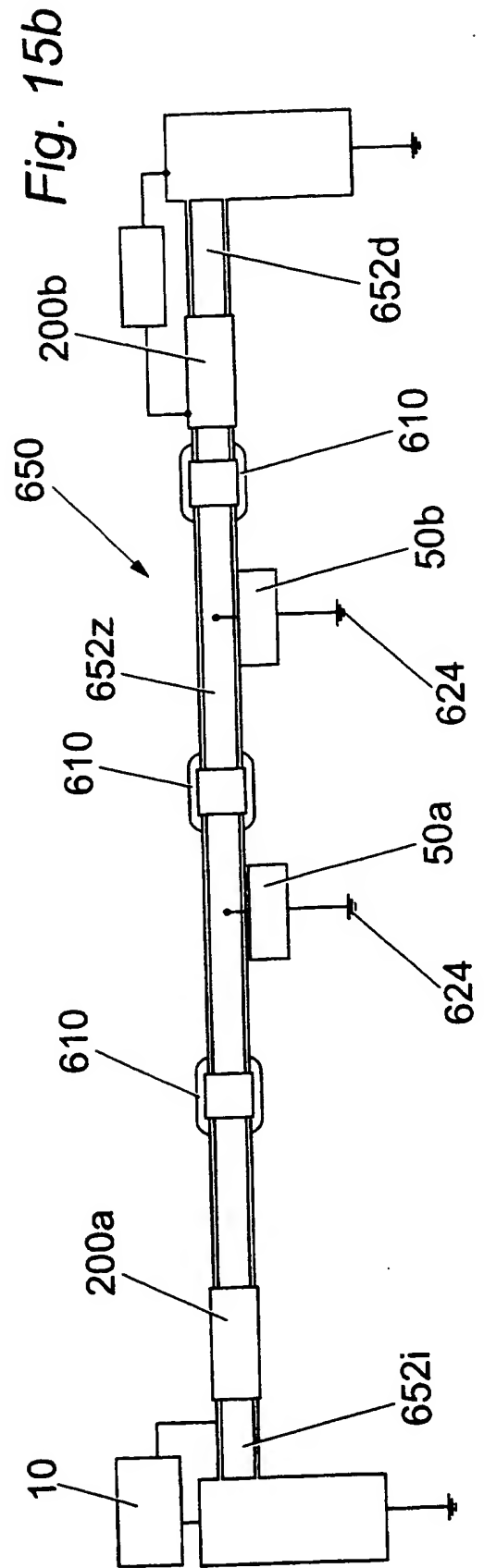
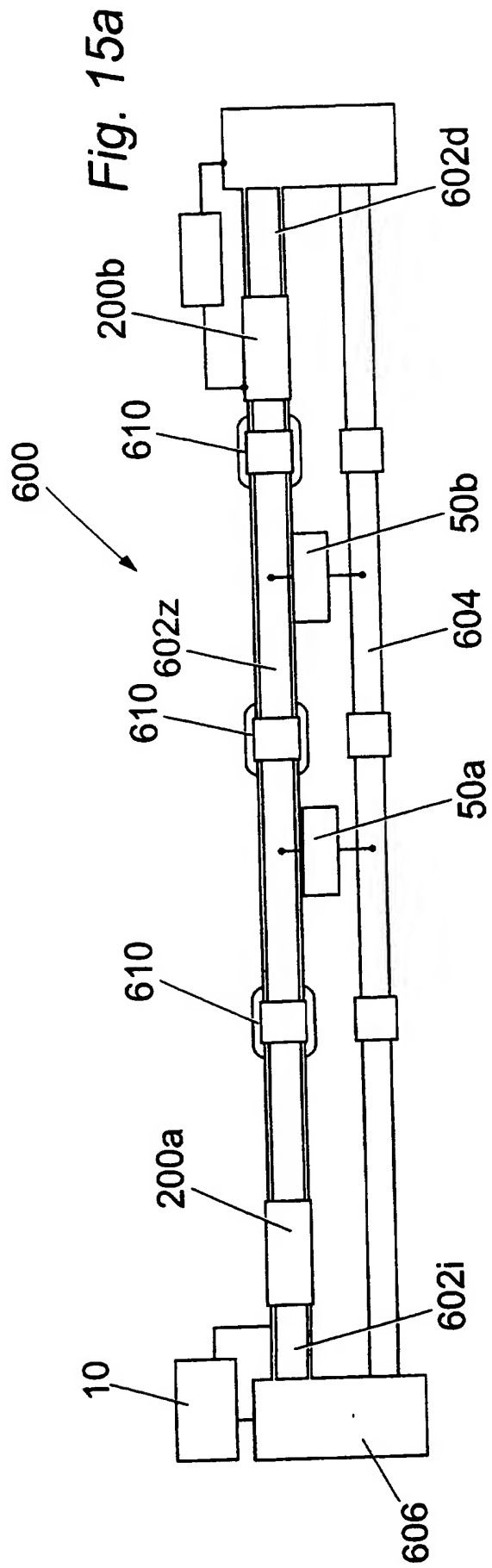


Fig. 14



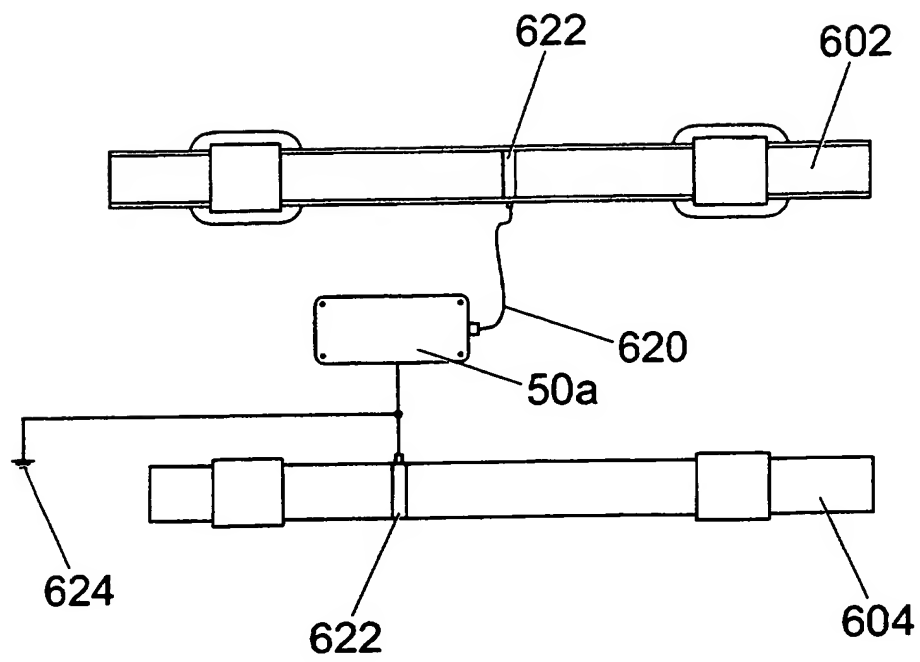


Fig. 16

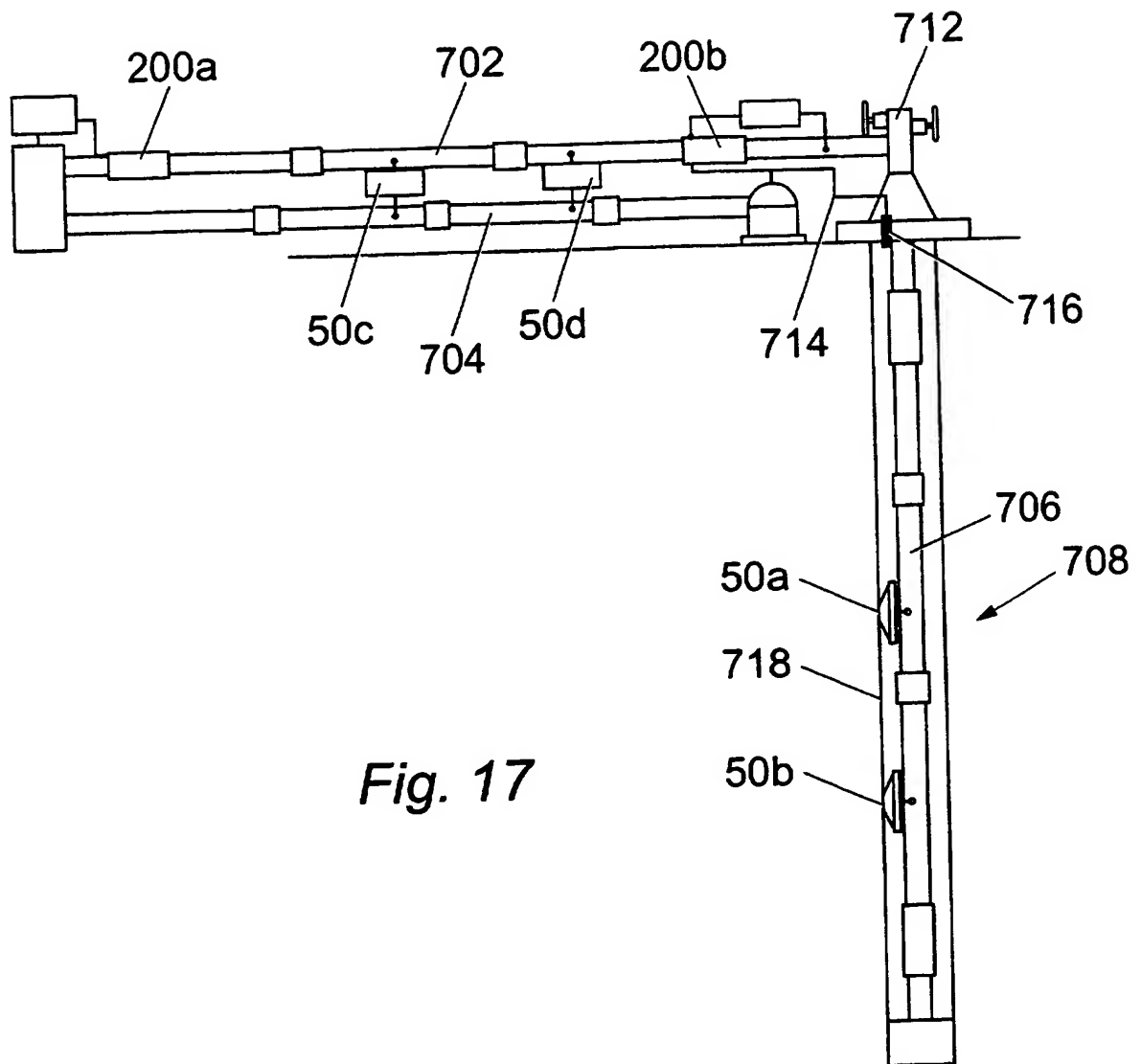


Fig. 17

1 **"Telemetry System"**

2

3 The present invention relates to a telemetry system,
4 particularly for use with an isolated pipeline or
5 tubing string.

6

7 Telemetry systems are typically used in the oil and
8 gas industry to transmit data from measuring devices,
9 sensors or the like located downhole to receivers
10 located at the surface. Conventional systems use
11 transmission mediums such as drilling fluid or mud in
12 which to transmit the signals between downhole and
13 surface locations. In addition, mono-conductor
14 instrument cables and single- or three-phase power
15 cables are often used to transmit data communications
16 in addition to their primary function.

17

18 Such conventional systems typically require at least
19 two individual power sources: one at the surface to
20 drive the receiving circuitry, and at least one

1 downhole to drive the remote circuitry. This
2 duplication of power sources increases the cost of
3 the system and may make the system unreliable, as
4 more components are required.

5
6 Furthermore, the power source downhole has
7 limitations associated with it in that the power
8 output from the source is restricted due to the
9 remoteness of the source. For example, the downhole
10 power source may comprise batteries that have a
11 limited power output and also a limited lifetime
12 before they must be either replaced or recharged.

13
14 A typical production completion requires a mono
15 conductor cable to be installed during the completion
16 in order to recover signals or perform control of
17 downhole devices. The installation of this cable
18 creates cost and complexity in the completion design.

19
20 According to a first aspect of the present invention
21 there is provided a telemetry system, the system
22 comprising a master unit, and at least one slave unit
23 remote from the master unit, the master and slave
24 units communicating via a transmission system,
25 wherein the telemetry system is capable of
26 transmitting power and data transmissions between the
27 units, and wherein the transmission system includes
28 an at least partially isolated tubing string or
29 pipeline.

30

1 According to a second aspect of the present
2 invention, there is provided a method of transmitting
3 power and data from a master unit to at least one
4 slave unit remote from the master unit, the master
5 and slave units communicating via a transmission
6 system, the transmission system including an at least
7 partially isolated pipeline or tubing string, the
8 method comprising the steps of

9 generating a power transmission at the master
10 unit;
11 generating a data transmission and synchronising
12 the data transmission with the power
13 transmission at the master unit;
14 transmitting the power and data transmissions
15 via the transmission system to the slave unit;
16 and
17 recovering the power and data transmissions at
18 the slave unit.

19
20 According to a third aspect of the present invention,
21 there is provided a method of transmitting data to a
22 master unit from at least one slave unit remote from
23 the master unit, the master and slave units
24 communicating via a transmission system, the
25 transmission system including an at least partially
26 isolated tubing string or pipeline, the method
27 comprising the steps of

28 generating a power transmission at the master
29 unit and transmitting the power transmission to
30 the slave unit;

1 recovering the power transmission at the slave
2 unit;
3 generating a data transmission at the slave unit
4 and synchronising the data transmission with the
5 power transmission;
6 transmitting the data transmission via the
7 transmission system to the master unit; and
8 recovering the data transmission at the master
9 unit.

10

11 Optionally, the method may include the further steps
12 of

13 dividing the data transmission into a series of
14 sub-windows;

15 transmitting a specified data transmission from
16 the slave unit to the master unit;

17 receiving the specified data transmission at the
18 master unit;

19 determining which of the sub-windows reliably
20 transmitted the specified data transmission.

21

22 The sub-windows that did not reliably transmit data
23 are typically filtered out or ignored for subsequent
24 transmissions. This technique may be used where the
25 transmission system is particularly noisy or may be
26 subject to interference and increases the chances of
27 reliably retrieving data transmissions.

28

29 According to a fourth aspect of the present
30 invention, there is provided a method of receiving
31 and converting power and data transmissions sent from

1 a master unit to at least one slave unit remote from
2 the master unit, the master and slave units
3 communicating via a transmission system, the
4 transmission system including an at least partially
5 isolated pipeline or tubing string, the method
6 comprising the steps of
7 receiving a power transmission at the slave
8 unit;
9 dividing the power transmission into two
10 channels;
11 rectifying and regulating the power transmission
12 in a first channel; and
13 recovering the data transmission in a second
14 channel.

15
16 According to a fifth aspect of the present invention,
17 there is provided a method of receiving data
18 transmitted by a master unit from at least one slave
19 unit remote from the master unit, the master and
20 slave units communicating via a transmission system,
21 the transmission system including an at least
22 partially isolated pipeline or tubing string, the
23 method comprising the steps of
24 receiving the data transmission at the master
25 unit;
26 filtering and conditioning the data
27 transmission; and
28 regenerating the transmitted data.

29
30 Optionally, the method may include the further steps
31 of

1 dividing the data transmission into a series of
2 sub-windows;
3 transmitting a specified data transmission from
4 the slave unit to the master unit;
5 receiving the specified data transmission at the
6 master unit;
7 determining which of the sub-windows reliably
8 transmitted the specified data transmission.

9
10 The sub-windows that did not reliably transmit data
11 are typically ignored for subsequent transmissions.
12 This technique may be used where the transmission
13 system is particularly noisy and increases the
14 chances of reliably retrieving data transmissions.

15
16 The pipeline or tubing string is typically
17 electrically isolated using at least one isolating
18 collar. The isolating collar typically comprises
19 first and second connectors, the first and second
20 connectors being threadedly coupled together.
21 Preferably, an electrical isolating material is
22 injected between the first and second connectors to
23 isolate the connectors from one another. The
24 insulating material is typically epoxy or the like.

25
26 The isolating collar typically includes means for
27 conveying electrical signals from outwith the collar
28 to the second connector. Thus, any pipeline or
29 tubing string coupled to the second connector is
30 typically capable of carrying electrical signals.

31

1 The pipeline or tubing string is typically coated
2 with an electrical isolating paint or the like to at
3 least partially isolate the pipeline or tubing
4 string.

5
6 The at least partially isolated pipeline or tubing
7 string typically comprises a surface pipeline or
8 tubing string. Alternatively, the at least partially
9 isolated pipeline or tubing string comprises a subsea
10 pipeline or tubing string, or a downhole pipeline or
11 tubing string. It will be appreciated that the at
12 least partially isolated pipeline or tubing string
13 may further comprise any combination of surface,
14 subsea or downhole pipelines or tubing strings.

15
16 The pipeline or tubing string typically includes a
17 first isolating collar at or near a source of fluid
18 flowing within the pipeline or tubing string.
19 Optionally, the pipeline or tubing string includes a
20 second isolating collar at or near a sink for the
21 fluid in the pipeline or tubing string. The master
22 unit is typically electrically coupled to the
23 pipeline or tubing string via the first isolating
24 collar. At least one slave unit is coupled to the
25 pipeline or tubing string, preferably at one or more
26 locations between said first and second isolating
27 collars.

28
29 System components including the master and slave
30 units may be earthed by being connected to a local
31 earth. Alternatively, a system earth and/or

1 electrical return path may be provided by other
2 tubulars such as a second pipeline or tubing string
3 or by a downhole, surface or subsea casing or the
4 like surrounding the pipeline or tubing string.

5
6 The slave unit typically comprises a mandrel, a slave
7 module, and an electrical return path. The mandrel
8 typically facilitates attachment of the slave unit to
9 the pipeline or tubing string. The mandrel is
10 typically clamped, or otherwise coupled, to the
11 pipeline or tubing string. The mandrel typically
12 facilitates transmission of the electrical power and
13 data transmissions from the pipeline to the
14 electronics of the slave unit.

15
16 The slave module typically houses the electronics of
17 the slave unit. The electrical return path typically
18 comprises a spring contact for engaging an earth
19 point. The earth point may be a local earth, a
20 further tubular such as a second pipeline, a subsea
21 or surface casing or a casing of a downhole well.

22
23 The slave unit is typically coupled to the pipeline
24 using a mandrel, pipeline clamp or other conventional
25 means. The pipeline or tubing string typically
26 includes a wellhead. A first isolating collar is
27 typically located at or near the wellhead. The
28 master unit is typically electrically coupled to the
29 first isolating collar (and thus the isolated
30 pipeline or tubing string) via a wellhead penetrator.
31 Alternatively, the master unit may be electrically

1 coupled to the pipeline by directly attaching the
2 output of the master unit to the pipeline using a
3 pipeline clamp, or other conventional attachment
4 means, for example a tubing clamp provided with a
5 cable coupling.

6
7 Pulse-width modulation is typically used to
8 facilitate data transmission from the master unit to
9 the slave unit. The power transmission is typically
10 modulated with the data transmission using pulse-
11 width modulation.

12
13 Frequency-shift keying (FSK) is typically used to
14 facilitate data transmission from the slave unit to
15 the master unit. The FSK frequencies are typically
16 superimposed on a carrier frequency. The carrier
17 frequency is typically the same frequency as the
18 power transmission frequency. The data transmission
19 is typically synchronised to the "high" cycle of the
20 power transmission. Alternatively, the data
21 transmission may be synchronised to the "low" cycle
22 of the power transmission, or optionally to both the
23 low and high cycles, or to any range of cycles to
24 circumvent the range of interference.

25
26 Where more than one slave unit is used, the data
27 transmission from the master unit to the slave unit
28 typically includes an address of the slave unit.
29 This allows several slave units to receive commands
30 from a single master unit.

31

1 The data transmissions preferably include data error
2 detection and/or correction. The data error
3 detection and/or correction typically comprise a
4 Hamming code, or other suitable technique.
5 Optionally where no DC or secondary power source is
6 in the system the master and slave may optionally be
7 DC coupled.

8
9 The master unit and/or the slave unit are preferably
10 ac coupled to the transmission system using
11 capacitors. Most preferably, the system employs
12 separate and discrete capacitors for this purpose.
13 This is known as capacitive coupling and allows any
14 dc bias within the transmissions to be blocked,
15 whilst passing any ac signals.

16
17 The master unit typically comprises a processor to
18 control the operation of the master unit; a power
19 waveform generator; and signal recovery and
20 conditioning circuitry.

21
22 The processor typically applies pulse-width
23 modulation to the power transmission when data
24 transmission is required from the master unit to the
25 slave unit. When not transmitting data, the
26 processor typically defaults the power transmission
27 to a 50% duty cycle.

28
29 The power waveform generator typically comprises an
30 analogue driver, and a power drive electrically
31 coupled to the analogue driver. The processor

1 typically applies the power transmission to the
2 analogue driver. The analogue driver typically
3 drives the power driver. The processor typically
4 controls the voltage amplitude of the power
5 transmission.

6
7 The analogue driver typically includes an isolating
8 circuit that isolates the power driver from the
9 processor. Typically, the analogue driver further
10 includes low voltage logic drivers to high voltage
11 driver stages, which in turn drive the power driver.
12 This prevents any damage being caused to the
13 processor.

14
15 The power driver typically comprises a field-effect
16 transistor (FET) based push-pull driver.
17 Alternatively, the power driver comprises a bi-polar
18 transistor based push-pull driver, or the like. The
19 power driver typically operates from a variable dc
20 power supply. The master unit typically includes the
21 variable dc power supply.

22
23 The signal recovery and conditioning circuitry
24 typically allows data transmitted by the at least one
25 slave unit to be extracted and recovered from the
26 transmission system. The signal recovery circuit
27 typically includes first and second data channels.
28 The first data channel typically includes a high-
29 speed switch; a filtering system; an automatic gain
30 control (AGC) stage; a comparator stage; and a first
31 counter.

1

2 The high-speed switch typically enables the data
3 transmission to be directed to the first and/or
4 second data channels when the power transmission is
5 high. Alternatively, the high-speed switch directs
6 the data transmission to the first and/or second data
7 channels when the power transmission is low, or when
8 the power transmission is both high and low.

9

10 The filtering system typically removes any noise and
11 background signals from the recovered data.

12 Typically, the filtering system comprises a pair of
13 selective filters. The selective filters typically
14 comprise broad bandpass filters. Alternatively, the
15 selective filters may comprise tuned filters. This
16 allows the filters to differentiate between the FSK
17 frequencies.

18

19 The AGC stage typically maintains the signal within a
20 set voltage amplitude range.

21

22 The comparator stage typically compares the voltage
23 amplitudes of the FSK frequencies.

24

25 The slave unit typically comprises a processor to
26 control the operation of the slave unit; rectifying
27 and regulating circuitry in a first channel; recovery
28 and conditioning circuitry in a second channel; and
29 frequency generating and mixing means.

30

1 The rectifying and regulating circuitry typically
2 comprises a half-bridge rectifier to rectify the
3 received power transmission into a dc voltage; and at
4 least one voltage regulator to regulate the dc
5 voltage.

6
7 The recovery and conditioning circuitry typically
8 comprises an amplifier and filtering system; and a
9 timer circuit. The amplifier and filtering system
10 typically amplifies or attenuates the signal, and
11 filters the signal. This boosts the amplitude of the
12 signal and removes any background noise or other
13 interference.

14
15 The frequency mixing and generating means typically
16 comprises a frequency-shift keying (FSK) generator;
17 an FSK mixer; and a line driver.

18
19 The slave unit typically includes an analogue signal
20 conditioning circuit, and at least one analogue-to-
21 digital convertor. The analogue conditioning circuit
22 allows the slave unit to receive and process signals
23 from a plurality of sensors, such as pressure
24 sensors, temperature sensors or the like.

25
26 The slave unit is typically capable of controlling
27 loads.

28
29 Embodiments of the present invention shall now be
30 described, by way of example only, with reference to
31 the accompanying drawings, in which :-

1 Fig. 1 schematically illustrates an embodiment
2 of a telemetry system coupled to an isolated
3 pipeline;
4 Fig. 2 schematically illustrates an embodiment
5 of a telemetry system similar to that of Fig. 1
6 with an additional slave unit;
7 Fig. 3 is a schematic block diagram of a
8 telemetry system in accordance with one
9 embodiment of the present invention;
10 Fig. 4 is a cross-sectional elevation of a first
11 embodiment of an isolating collar for
12 electrically isolating a pipeline;
13 Fig. 5 is a cross-sectional elevation of a
14 second embodiment of an isolating collar for
15 electrically isolating a pipeline, including an
16 electrical connector;
17 Fig. 6a shows an exemplary power waveform for
18 transmitting power from a master unit at the
19 surface to a slave unit downhole;
20 Fig. 6b shows an exemplary signal transmit
21 waveform for transmitting data from a slave unit
22 to a master unit using frequency-shift keying
23 (FSK);
24 Fig. 7a shows the power waveform of Fig. 2a
25 modulated using pulse-width modulation for
26 transmitting both power and data from a master
27 unit at the surface to a slave unit downhole;
28 Fig. 7b shows how data is encoded in the
29 modulated waveform of Fig. 3a;

1 Fig. 8a shows an exemplary power waveform
2 transmitted on the isolated pipeline to which
3 the telemetry system of Fig. 1 is attached;
4 Fig. 8b shows an exemplary power waveform for
5 transmitting power from a master unit at the
6 surface to a slave unit downhole;
7 Fig. 8c shows an exemplary signal transmit
8 waveform for transmitting data from a slave unit
9 to a master unit using frequency-shift keying
10 (FSK);
11 Fig. 8d shows an enlarged portion of the
12 waveform of Fig. 8c;
13 Fig. 9 is a schematic illustration of an oilwell
14 that includes an isolated production tubing;
15 Figs 10a and 10b illustrate two examples of a
16 wellhead penetrator;
17 Fig. 11 is a schematic illustration of a portion
18 of the oilwell of Fig. 9 showing connection of
19 an electrical signal to a pipeline or tubing
20 string;
21 Fig. 12 is a cross-sectional elevation
22 illustrating an embodiment of a slave unit of
23 the telemetry system of Fig. 2 attached to an
24 isolated pipeline or tubing string;
25 Figs 13a and 13b schematically illustrate a
26 subsea pipeline installation with dual and
27 single pipelines, respectively, with the
28 telemetry system of Fig. 2 attached thereto;
29 Fig. 14 is a cross-sectional elevation
30 illustrating a method of attaching a slave unit
31 to a subsea pipeline;

1 Figs 15a and 15b schematically illustrate a
2 surface pipeline installation with dual and
3 single pipelines, respectively, with the
4 telemetry system of Fig. 2 attached thereto;
5 Fig. 16 schematically illustrates a method of
6 attaching a slave unit to a surface pipeline;
7 and
8 Fig. 17 schematically illustrates an oilwell
9 that has a subsea or surface pipeline attached
10 thereto.

11
12 Referring to the drawings, Fig. 1 shows an
13 illustrative embodiment of an exemplary embodiment of
14 a telemetry system coupled to an isolated pipeline or
15 the like according to the present invention. As
16 shown more clearly in Fig. 3, the telemetry system
17 comprises a master unit 10 and a slave or node unit
18 50. The master and slave units 10, 50 communicate
19 with each other via a transmission system 12, i.e. a
20 pipeline or well tubing string 100 (Fig. 1), that is
21 at least partially isolated from earth, e.g. by means
22 of at least one isolating collar 200 (Figs 4 and 5).
23 In the embodiment shown in Fig. 1, a first isolating
24 collar 200a is located at a first end of the pipeline
25 100. Optionally, a second isolating collar 200b may
26 be positioned at a distal end of the pipeline 100 at
27 the end of a transmission zone, the transmission zone
28 being defined between the first and second isolating
29 collars 200a, 200b.

30

1 The master unit 10 typically includes a power supply
2 and controller unit that generates an electrical
3 power supply, and also transmits data to and receives
4 data from the remote slave unit 50. The slave unit
5 50 is powered by the master unit 10 as will be
6 described hereinafter, and can carry out control and
7 monitoring functions from where it is coupled to the
8 isolated pipeline 100. The master and slave units
9 10, 50 require the electrical circuit to be completed
10 by connection to an electrical ground or earth point,
11 as schematically shown in Fig. 1.

12
13 In this way, sensors, instrumentation systems or load
14 actuators coupled to the slave unit 50 can be
15 monitored and the load actuators can be controlled
16 from the master unit 10 using only the pipeline 100
17 for transmission of power and data transmissions.
18 Further the slave unit 50 can be coupled at any point
19 in the isolated portion of the pipeline 100 (i.e. the
20 transmission zone defined between isolating collars
21 200a, 200b).

22
23 As shown in Fig. 2, the system can support more than
24 one slave unit (i.e. slave units 50a, 50b) coupled to
25 the isolated portion of the pipeline 100. The system
26 can support multiple slave units 50a, 50b etc, with
27 each slave unit 50a, 50b etc, being coupled to the
28 pipeline 100 at any point in the isolated portion.

29
30 The system may be configured to transmit either
31 solely the power supply transmissions from the master

1 unit 10 to the slave unit 50, or to include data
2 transmissions in addition to transmitting power. The
3 data transmission is typically synchronised to the
4 power supply transmission and/or with a secondary and
5 larger power source running in parallel with the
6 power supply and data transmissions from the master
7 unit 10 to the slave units 50. This secondary power
8 source can either be used for pipeline heating and/or
9 powering large power actuators and motors attached to
10 the isolated portion of the pipeline 100.

11
12 The master unit 10 is typically located at the
13 surface, and the slave unit 50 is typically located
14 remote from the master unit 10, for example in a
15 borehole, oilwell, subsea installation or the like.
16 The location of the master unit 10 is dependent upon
17 the particular application, and the relative
18 positions of the master unit 10 and the slave unit(s)
19 50 described herein are by way of example only.

20
21 It should be noted that a number of slave units 50
22 may be coupled to the transmission system 12 (i.e.
23 the pipeline 100), and the operation of each slave
24 unit 50 controlled by the master unit 10 at the
25 surface. It should also be noted that the system may
26 use more than one master unit 10 if control of the
27 slave unit(s) 50 is required from more than one point
28 in the system.

29
30 The master and slave units 10, 50 are advantageously
31 coupled to the isolated pipeline 100 using capacitive

1 coupling. Discrete capacitors 14, 52 (Fig. 3) are
2 coupling or blocking capacitors that couple a signal
3 from a power source (discussed later) to the isolated
4 pipeline 100. Capacitors 14, 52 block any direct
5 current (dc) bias that may be applied to the signal,
6 but do not affect any alternating current (ac) signal
7 that is simultaneously transmitted. When considering
8 dc, the capacitors 14, 52 act as open circuits as, at
9 zero frequency (dc), the reactance of a capacitor is
10 infinite.

11
12 Referring now to Fig. 3, the master unit 10 includes
13 a power input stage 16 that provides power for the
14 telemetry system, and may be either an ac or dc power
15 source. The power input stage 16 is electrically
16 coupled to at least one (and preferably a plurality
17 of) dc voltage regulators 18. Voltage regulators 18
18 provide local power supplies (dc) for the circuitry
19 in the master unit 10. Generally, different
20 components within the master and slave units 10, 50
21 operate using a plurality of different voltages,
22 depending upon the various specifications of these
23 components.

24
25 The master unit 10 includes a processor 20 that,
26 among other functions, controls the operation of the
27 telemetry system. One output of the processor 20 is
28 electrically coupled to an analogue driver stage 22,
29 the driver stage 22 being electrically coupled to a
30 high voltage ac power driver 24. The output of the

1 power driver 24 is electrically coupled (via the
2 coupling capacitor 14) to the isolated pipeline 100.

3
4 The power driver 24 may be a field-effect transistor
5 (FET) or a bi-polar transistor based push-pull drive
6 stage, that typically operates using a variable but
7 relatively large dc voltage power supply. The dc
8 power supply is typically rated from 20 to 500 volts,
9 although voltages outwith this range may also be
10 used. The particular voltage used is dependent upon
11 the loading conditions and losses in the isolated
12 pipeline 100, and can be varied accordingly.

13
14 The power driver 24 is preferably electrically
15 isolated from the processor 20 to prevent damage to
16 the processor 20. Thus, the analogue driver stage 22
17 includes isolating circuits and low voltage logic
18 drivers to a high voltage drive stage, which in turn
19 drives the gates of the FET or bi-polar transistor
20 power driver 24.

21
22 The master unit 10 further includes a signal recovery
23 circuit 26 that retrieves data transmitted (via the
24 isolated pipeline 100 as will be described) by the
25 slave unit 50. The processor 20 controls operation
26 of the signal recovery circuit 26. The recovered
27 data from the signal recovery circuit 26 is processed
28 by a filtering system 28 that further extracts the
29 received information from any noise or other
30 background interference mixed with the recovered data
31 from the slave unit 50.

1

2 The output from the filtering system 28 is fed into a
3 signal conditioning unit that includes an automatic
4 gain control (AGC) stage 30, and a comparator stage
5 32. The output of the comparator stage 32 is fed
6 into a first counter 34. The first counter 34 is
7 electrically coupled to the processor 20, so that the
8 processor 20 can read the value in the first counter
9 34.

10

11 In certain embodiments of the present invention, the
12 raw signal from the slave unit 50 is additionally fed
13 into a second data channel that includes a signal
14 recovery circuit 36 to extract data from the power
15 transmission on the isolated pipeline 100. The
16 output from the second signal recovery circuit 36 is
17 fed into a timer circuit 38 that performs pulse-width
18 measurements on the data extracted from the power
19 transmission. The output of the timer circuit 38 is
20 fed into a second counter 40, the value in the
21 counter being read by the processor 20.

22

23 A remote station (not shown) typically controls
24 operation of the master unit 10, and is electrically
25 coupled to the master unit 10 via a serial data link
26 46, such as an RS232/485 serial data port. The
27 remote station may be, for example, a personal
28 computer located remotely from the master unit 10.

29

30 The slave unit 50 includes a half-wave rectifier and
31 heat dissipation unit 54. This unit 54 extracts

1 power transmitted via the isolated pipeline 100 to
2 the slave unit 50 as will be described. As with the
3 master unit 10, the slave unit 50 has a matched pair
4 of voltage regulators 56 and a plurality of low
5 voltage dc regulators 58 to provide local power
6 supplies for the circuitry in the slave unit 50.

7
8 The slave unit 50 is provided with a processor 60 to
9 control the operation thereof. The processor 60 is
10 electrically coupled to a line driver 62 that
11 transmits data onto the isolated pipeline 100.

12
13 In certain embodiments, the slave unit 50 transmits
14 data to the master unit 10 (via the isolated pipeline
15 100) using frequency-shift keying (FSK), as will be
16 described. A frequency generator 64 is used to
17 generate the two required frequencies F_1 , F_2 . The
18 frequencies F_1 , F_2 are then mixed by a frequency mixer
19 66 to combine data from the processor 60 with carrier
20 frequency F_c and the modulating frequencies F_1 , F_2 .

21
22 The slave unit 50 further includes a signal recovery
23 circuit 68 to extract data from the isolated pipeline
24 100 generated by the master unit 10. A timer circuit
25 70 is used to perform pulse-width measurements on the
26 data extracted by the signal recovery circuit 68.

27
28 The slave unit 50 is provided with an analogue signal
29 conditioning circuit 74, and a plurality of analogue-
30 to-digital (A/D) convertors 76. The analogue
31 conditioning circuit 74 and the A/D convertors 76

1 allow a plurality of different types of
2 instrumentation and/or sensors (not shown) to be
3 coupled to the system. Thus, the slave unit 50
4 monitors these instruments and sensors and transmits
5 data procured by them to the master unit 10 for
6 collection and analysis.

7
8 The slave unit 50 can accept a wide range of sensors,
9 and any electronic sensor that can be conditioned and
10 measured using a processor can be used with the
11 system. Typical sensor inputs to the analogue signal
12 conditioning circuit 74 comprise either analogue
13 sensors with voltage outputs, or those with frequency
14 outputs. Typical examples of analogue sensors that
15 may be used to collect information include pressure
16 sensors, temperature sensors, accelerometers and
17 fluid depth sensors (resistive or capacitive).
18 Typical examples of frequency or pulse output
19 sensors, include shaft speed indicators, high
20 accuracy pressure and temperature sensors and flow
21 meters. These are exemplary only, and the range of
22 applications will be apparent to those skilled in the
23 art.

24
25 The analogue sensors coupled to the system can be
26 powered from the low-level regulators 58 in the slave
27 unit 50. The voltage or current outputs from the
28 sensors would be amplified or filtered in the
29 analogue signal conditioning circuit 74 if required,
30 and the conditioned outputs fed into the multiplexed

1 A/D convertor 76, the outputs then being fed to the
2 processor 60 for transmission in digital format.

3

4 The data system architecture within the system
5 typically operates using 16 or 24 bit data words for
6 transmission, and read values can be transmitted to
7 the master unit 10 as A/D counts in either 16 or 24
8 bit words, depending upon the required accuracy and
9 resolution of the measurements.

10

11 Where pulse or frequency signals are output from the
12 sensors, a reciprocal counter could be used to
13 measure the frequency locally in the analogue signal
14 conditioning unit 74. In this embodiment, the
15 processor 60 typically forms part of the reciprocal
16 counter to minimise or reduce the electronics
17 required in the slave unit 50.

18

19 In addition to sensor measuring capabilities, the
20 system could be utilised to control loads. As the
21 system in certain embodiments can facilitate two-way
22 communication, any electronic control that can be
23 implemented with the local processor 60 can be
24 implemented using the telemetry system. For example,
25 the slave unit 50 may be used to control solenoids to
26 operate and control actuators, hydraulic valve
27 mechanisms, motors that open valves, or other similar
28 functions.

29

30 Operation of the telemetry system shall now be
31 described. The processor 20 in the master unit 10

1 applies a power waveform to the driver 22 under
2 command from the remote station. The driver 22
3 drives the power driver 24 that applies a square-wave
4 power waveform (Fig. 6a), the power waveform being
5 transmitted to the isolated pipeline 100 through the
6 coupling capacitor 14.

7
8 Fig. 6a shows an exemplary power signal waveform that
9 is transmitted from the master unit 10 to the slave
10 unit 50 via the isolated pipeline 100. The frequency
11 of the waveform may be any suitable frequency; a
12 typical frequency range may be from 10 millihertz
13 (mHz) to 6 kilohertz (kHz) although frequencies
14 outwith this range may be used. Where there is even
15 a moderate bandwidth on the isolated pipeline 100,
16 the frequencies used to transmit power from the
17 master unit 10 to the slave unit 50 will be from 100
18 Hz to 100 kHz.

19
20 The amplitude of the waveform is variable and is
21 dependent upon the loading conditions and losses of
22 the isolated pipeline 100. The processor 20 using a
23 regulator (one of the plurality of regulators 18)
24 controls the voltage amplitude of the square-wave
25 power waveform (Fig. 6a). By controlling the
26 amplitude of the power waveform using a processor 20,
27 the amplitude may be adjusted either manually or
28 automatically to set and keep the amplitude constant
29 in varying operating conditions.

30

1 The slave unit 50 receives an attenuated power input
2 from the isolated pipeline 100 through the coupling
3 capacitor 52. Any background noise or other
4 interference will be added to the power signal during
5 transmission from the master unit 10 to the slave
6 unit 50, thus resulting in a degraded signal being
7 detected at the slave unit 50. The power is
8 rectified through the half-bridge rectifier 54 and is
9 then regulated in the regulating units 56, 58 to
10 provide the local power supplies for the various
11 circuitry within the slave unit 50.

12

13 Fig. 6b illustrates how data may be transmitted from
14 the slave unit 50 to the master unit 10. Data is
15 transmitted using frequency-shift keying (FSK) in a
16 continuous stream during data transmission. Two FSK
17 frequencies F_1 , F_2 are superimposed on a carrier
18 frequency F_c . In the example shown in Fig. 6b, the
19 carrier frequency F_c is the same frequency as the
20 power waveform of Fig. 6a, and the data transmission
21 is synchronised to the "high" cycle of the power
22 waveform shown in Fig. 6a. It should be noted that
23 the data may be synchronised to the "low" cycle, or
24 to both the high and low cycles. This
25 synchronisation allows the master unit 10 to
26 correctly detect the data transmission from the slave
27 unit 50.

28

29 The frequencies used to transmit data from the slave
30 unit 50 are typically several hundred kilohertz
31 (kHz). For example, the transmit frequencies F_1 , F_2

1 from the slave unit 50 to the master unit 10 may be
2 300 kHz for a logic one and 100 kHz for a logic zero.
3 Thus, if a logic one is to be transmitted, then the
4 higher of the two FSK frequencies (i.e. F_1) will be
5 transmitted for the duration of the high cycle of the
6 power waveform, and if a logic zero is to be
7 transmitted, the lower of the two FSK frequencies
8 (i.e. F_2) is transmitted for the duration of the high
9 cycle of the power waveform.

10

11 The two FSK frequencies F_1 , F_2 are preferably not
12 multiples of one another to minimise the occurrence
13 of false detections. The two frequencies F_1 , F_2 are
14 typically also at least a factor of two different.
15 Although this increases the amount of bandwidth
16 required on the isolated pipeline 100, it allows for
17 the recovery of highly attenuated signals. Where
18 there is significant inductance on the isolated
19 pipeline 100, much lower frequencies may be used.
20 This reduces the speed of the system, but does not
21 affect the ability of the system to transmit and
22 receive data. Low carrier frequencies may be used
23 (in the order of a few hertz) with very high
24 frequency data carriers to increase data recovery in
25 noisy environments, such as that downhole. Where low
26 frequencies are required, the system may also be used
27 with fractions of a hertz for the carrier, and a
28 logic zero frequency of 100 Hz and a logic one
29 frequency of 350 Hz, for example.

30

1 Power across the slave unit 50 can be adjusted to
2 provide the power supplies necessary for the type of
3 electronics being operated. For example, for any
4 instrument systems being operated downhole, ± 15 volts
5 is normally required. Thus, the ac power across the
6 (downhole) slave unit 50 will be in the order of ± 30
7 volts to maintain the power supplies at a stable
8 level (due to losses etc).

9
10 The data recovery circuit 26 in the master unit 10
11 operates as follows. The low-level signal
12 transmitted by the slave unit 50 is sensed using a
13 sense resistor 42. The signal from the slave unit 50
14 develops a voltage across the sense resistor 42 as
15 the output of the push-pull power driver 24 is
16 effectively an ac ground.

17
18 The value of sense resistor 42 is typically twenty
19 times the resistive value of the isolated pipeline
20 100. For example, if the resistive value of the
21 isolated pipeline 100 is 10 ohms (Ω) from a master
22 injection point 44 (Fig. 3) to the slave unit 50,
23 then the sense resistor 42 would have a value of
24 200Ω . The value of this sense resistor 42 can be
25 chosen to match the particular isolated pipeline 100.

26
27 The raw signal from the sense resistor 42 is then
28 processed by the first data channel that includes the
29 first signal recovery circuit 26, and is fed through
30 an analogue high speed switch (not shown, but forms
31 part of the signal recovery circuit 26). The

1 processor 20 or a local zero-crossing detection
2 circuit or the like, enables data to be directed to
3 the first data channel only when the power waveform
4 is high, thus facilitating the synchronisation. The
5 data channel then only receives and processes valid
6 segments of the recovered data. It should be noted
7 that the triggering mechanism for directing data into
8 the data channel may be configured to allow
9 transmission when the power waveform is low, or both
10 when it is high and low.

11

12 The sampled data is then fed through the filtering
13 system 28 that, in simple applications, typically
14 comprises a single broad bandpass filter. In noisy
15 applications, it is preferable to use a pair of
16 selective filters designed for each transmit
17 frequency F_1 , F_2 . It may also be necessary in
18 exceptionally noisy environments to use tuned
19 filters.

20

21 The signal recovered from the filtering system 28 is
22 then fed through an automatic gain control (AGC)
23 stage 30. The AGC stage 30 maintains the amplitude
24 of the recovered signal within a set amplitude range.
25 The frequency response of the AGC stage 30 is
26 typically sufficient to allow the AGC amplifier to
27 correct for changes in amplitude over one cycle of
28 either the transmission medium power frequency or the
29 telemetry system power frequency, whichever is the
30 higher frequency. The AGC stage 30 performs two
31 functions. It compensates for the difference in

1 amplitude from the high carrier to the low carrier
2 frequency received (i.e. the difference in amplitudes
3 between F_1 and F_2). In addition, there may also be
4 variations in the amplitude of the received signal
5 over the time period of the high cycle of the power
6 waveform frequency (i.e. variations in amplitude of
7 the signal during a single bit transmission). The
8 AGC stage 30 must be able to react quickly enough to
9 compensate for these changes without becoming
10 unstable. Thus, the frequency response of the AGC
11 stage 30 is related to the frequency of the power
12 waveform, and the bandwidth of the AGC stage 30 is
13 typically ten times greater than the power waveform
14 frequency (i.e. ten times greater than the baud
15 rate).

16
17 The recovered signal is then fed into the comparator
18 stage 32, the output of which is fed into the first
19 counter 34. The comparator stage 32 compares the
20 signal level of each of the two FSK frequencies F_1 ,
21 F_2 to establish which is present. The output of the
22 comparator stage 32 is a signal that contains either
23 one of the two FSK frequencies F_1 , F_2 . The first
24 counter 34 then counts the number of pulses in the
25 signal from the comparator stage 32, and the
26 processor 20 reads the value in the first counter 34
27 to determine which of the two FSK logic frequencies
28 F_1 , F_2 are present (i.e. either the frequency
29 relating to a logic one or zero).

1 The slave unit 50 transmits in a continuous stream of
2 digital data (i.e. ones and zeros), with each high
3 cycle of the power waveform containing one of the two
4 FSK frequencies F_1 , F_2 representing either a logic
5 one or zero. The process is thus continued for each
6 high cycle of the power waveform to determine whether
7 a one or a zero was transmitted in each high cycle.
8 Once the processor 20 has determined whether a one or
9 a zero was sent in each high cycle, the processor 20
10 may reconstruct the transmitted digital data from the
11 slave unit 50.

12
13 The slave unit 50 may also transmit bursts of
14 transmitted data in a poll response mode. In the
15 poll response mode, there are three states for
16 transmission from the slave unit 10 to the master
17 unit 50: a logic one, a logic zero and a "none"
18 state. Thus, when not requested to transmit data the
19 slave unit 50 ceases transmission. This poll
20 response mode is typically used where multiple slave
21 units 50 are operating on the same transmission
22 system.

23
24 Figs 7a and 7b illustrate a power and data
25 transmission waveform respectively, for the
26 transmission of data from the master unit 10 at the
27 surface to the slave unit 50. Data is transmitted
28 from the master unit 10 to the slave unit 50 using
29 pulse-width modulation. Use of this technique allows
30 the signal recovery circuitry in the slave unit 50
31 located downhole to be less complex than that in the

1 master unit 10, thus reducing the size, cost and
2 power consumption of the slave unit 50.

3

4 Fig. 7a illustrates the power waveform transmitted
5 when data is being transmitted from the master unit
6 10 to the slave unit 50. In order to transmit
7 digital data, the width of the pulses in the waveform
8 are modified to represent either a digital zero or
9 one. This technique is termed pulse-width
10 modulation. Fig. 7b illustrates the difference in
11 pulse-widths between a logic one and zero as an
12 example. There are typically three different pulse-
13 widths (frequencies) used, each relating to either a
14 logic one, a logic zero or an idle state. The idle
15 state is typically used to aid specific command
16 recovery in the slave units 50. For example, where
17 there is more than one slave unit 50 coupled to the
18 system, each unit 50 remains in the idle state and
19 polls the data transmissions from the master unit 10
20 until it receives a command intended for that
21 particular unit 50 identified by the command string.

22

23 When data is transmitted from the master unit 10 to
24 the slave unit 50 using pulse-width modulation, the
25 signal received at the slave unit 50 is fed through a
26 second ac coupling capacitor 72 into a signal
27 recovery circuit 70, that includes an amplifier and
28 filtering system. The signal is amplified or
29 attenuated, depending upon the application.

30

1 The relative frequency of the main transmission
2 system power, and the frequency of the telemetry
3 power carrier F_c determine the value of the coupling
4 capacitor 72. The value is chosen so that the
5 capacitive decoupling acts as a high pass filter to
6 remove substantially all of the transmission system
7 power waveform whilst recovering as much of the
8 telemetry system power waveform as possible.

9

10 The requirement to either attenuate or amplify the
11 signal after decoupling depends upon the attenuation
12 of the high pass filter described above. As the
13 signal is superimposed on the power waveform, it will
14 have a substantial peak-to-peak voltage at the slave
15 unit 50 connection. If this large voltage signal is
16 decoupled without any substantial losses, the
17 recovered signal fed to the first stage amplifiers in
18 the signal recovery circuit 68 will exceed the supply
19 rails and will thus require to be attenuated.

20

21 However, if the signal is decoupled with a
22 substantial amount of low frequency rejection (i.e.
23 through a high pass filter), then the signal fed to
24 the first stage amplifier will be relatively small
25 and will thus require to be amplified. The
26 requirement to amplify or attenuate the signal is
27 dependent upon the relative frequency of the power
28 waveform to the transmission medium frequency.

29

30 The recovered and filtered signal is then fed into a
31 processor-controlled timer circuit 70. The timer

1 circuit 70 may be replaced by a re-triggered
2 monostable. The timer circuit 70 allows pulse-width
3 measurements to be taken to determine whether a one
4 or a zero was sent. The processor 60 can then
5 reconstruct the data transmission from the master
6 unit 10 to the slave unit 50 by analysing and
7 recording each pulse-width in turn to determine the
8 sequence of ones and zeros in the data transmission.

9
10 Data sent by the master unit 10 to the slave unit 50,
11 or vice versa, is typically encrypted by use of a
12 Hamming Code, or other suitable data error detection
13 and correction encoding scheme. The data from the
14 master unit 10 may also include the address of the
15 slave unit 50 in the command string so that several
16 slave units 50 may receive different and individual
17 commands from a single master unit 10.

18
19 Where the isolated pipeline 100 is particularly noisy
20 or there is a large degree of background
21 interference, it is often not possible to determine
22 from the method described above whether a logic one
23 or zero was transmitted. To overcome this, the
24 recovered data is not measured as one of two
25 frequencies in windows delineated from the power
26 waveform, but each data detection window that is seen
27 by the processor 20 at the surface is sub-divided
28 into several sub-windows. Figs. 8a to 8d illustrate
29 this technique.

30

1 To operate correctly using this sub-dividing
2 technique, it is preferable to use a second data
3 channel within the master unit 10 that includes the
4 second signal recovery circuit 36, the timer circuit
5 38 and the second counter 40.

6
7 The telemetry system may be coupled to any isolated
8 pipeline 100 or a tubing string. For example, it may
9 be coupled to an existing pipeline that is used to
10 recover hydrocarbons from a borehole, subsea well or
11 the like. Fig. 8a shows a typical power waveform
12 that may be present on the isolated pipeline 100 and
13 may be, for example, a power waveform that is driving
14 a downhole motor. The second data channel in the
15 master unit 10 is used to determine the fundamental
16 operating frequency of the power waveform for the
17 downhole motor. The processor 20 within the master
18 unit 10 uses the second counter 40 to establish the
19 frequency at which the power waveform on the isolated
20 pipeline 100 is operating, using a similar technique
21 as described above to determine whether a zero or a
22 one was sent. The processor 20 then synchronises the
23 transmitted power for the slave unit 50 (waveform
24 shown in Fig. 8b) to the same frequency, or a
25 multiple thereof, as the power frequency of the
26 isolated pipeline 100. Thus, the power and data
27 transmissions are synchronised to the frequency of
28 the power on the isolated pipeline 100 over which
29 they are transmitted (i.e. they are synchronised with
30 the source of the noise which can cause a loss of
31 signal) thus reducing the effect of the noise.

1

2 Fig. 8b shows an exemplary power waveform for
3 transmission of power and/or data from the master
4 unit 10 to the slave unit 50. The waveform shown in
5 Fig. 8b is similar to that shown in Fig. 6a and may
6 operate over the same frequency range (i.e. in the
7 order of a few mHz to several kHz).

8

9 Fig. 9c illustrates the data transmission from the
10 slave unit 10 downhole to the master unit 50 at the
11 surface. The waveform is similar to that shown in
12 Fig. 6b wherein the data transmission is superimposed
13 upon and synchronised to the high cycle of the power
14 waveform. Although the example shows data being
15 superimposed on and synchronised to the high cycle,
16 it should be noted that data could also be
17 superimposed on and synchronised to the low cycle or
18 both.

19

20 Frequency-shift keying (FSK) is used to transmit data
21 from the slave unit 50 to the master unit 10. In the
22 example shown in Fig. 8c, F_1 that represents a logic
23 one is 200 kHz and F_2 that represents a logic zero is
24 90 kHz. As with the previous example, the two FSK
25 frequencies F_1 , F_2 are preferably not multiples of one
26 another to minimise the occurrence of false
27 detections. The two frequencies F_1 , F_2 are typically
28 also at least a factor of two different. Although
29 this increases the amount of bandwidth required on
30 the isolated pipeline 100, the system allows for the
31 recovery of highly attenuated signals. Where there

1 is significant inductance on the isolated pipeline
2 100, much lower frequencies may be used. This
3 reduces the speed of the system, but does not affect
4 the ability of the system to transmit and receive
5 data. Low carrier frequencies may be used (in the
6 order of a few hertz) with very high frequency data
7 carriers to increase data recovery in noisy
8 environments, such as those downhole. Where low
9 frequencies are required, the system may also be used
10 with fractions of a hertz for the carrier, and a
11 logic zero frequency of 100 Hz and a logic one
12 frequency of 350 Hz, for example.

13

14 The frequency used to transmit data to and from the
15 slave unit 50 is typically several hundred kilohertz
16 (kHz). For example, the transmit frequencies F_1 , F_2
17 from the slave unit 50 to the master 10 may be 200
18 kHz for a one and 90 kHz for a zero. Thus, if a
19 logic one is to be transmitted, then the higher of
20 the two FSK frequencies F_1 (i.e. 200 kHz) will be
21 transmitted for the duration of the high cycle of the
22 power waveform, and if a logic zero is to be
23 transmitted, the lower of the two FSK frequencies F_2
24 (i.e. 90 kHz) is transmitted for the duration of the
25 high cycle of the power waveform.

26

27 However, where the isolated pipeline 100 is
28 particularly noisy, for example where the
29 transmission system 12 is also used to drive a
30 downhole motor, it may not be possible to determine
31 whether a logic one or zero was sent from the basic

1 counter discrimination technique. A further
2 technique is used to aid in discriminating between a
3 logic one and zero that sub-divides each of the data
4 windows in the data transmission waveform into a
5 series of sub-windows. An example of a sub-window is
6 shown in Fig. 8d, which is an enlarged view of one of
7 the data windows from the waveform in Fig. 8c. The
8 data window is sub-divided into a number of sub-
9 windows, such as ten shown in Fig. 8d. Each of the
10 ten sub-windows is then studied and measurements
11 taken to determine which of the two FSK frequencies
12 (i.e. F_1 or F_2) is present within that sub-window.

13
14 Every high period (the receive window) of the slave
15 unit power waveform (Fig. 8c) is segmented in the
16 processor code into smaller time slots (typically ten
17 per receive window). When the system is first
18 initiated, or on command from the master unit 10, the
19 slave unit 50 transmits a specified pattern of ones
20 and zeros to calibrate the transmission data windows.
21 The master unit 10 receives and processes this
22 pattern and determines from the pattern received the
23 reliability of the recovered data. The reliability
24 of the recovered data indicates which of the sub-
25 windows in the received window has reliably
26 transmitted a one or a zero. The sub-windows in
27 which a one or a zero cannot be reliably recovered
28 are mapped as being "not usable" in the memory of the
29 processor 20 and are thus not used for data recovery.
30 In this way, the reliability of the system is
31 increased, as the test transmission allows the system

1 to assess which sub-windows are being affected by
2 noise and other interference, these sub-windows then
3 being ignored for future transmissions. This
4 technique allows for enhanced reliability and also
5 the ability to allow the system to be calibrated to
6 particular environments.

7
8 Thus, this technique provides a method of data
9 transmission and recovery that uses sub-divided and
10 synchronised data recovery windows to enhance the
11 noise immunity of the system, and also the use of a
12 calibrating pattern to allow the master unit 10 to
13 determine the reliable portions of the recovered data
14 transmitted by the slave unit 10.

15
16 Referring to Fig. 4, isolating collar 200 is used to
17 provide electrical isolation whilst maintaining
18 pressure sealing in the pipeline 100. Isolating
19 collar 200 is described in US Patent Nos 4,861,074
20 and 4,716,960 assigned to Production Technologies
21 Inc, the entire disclosure of these patents being
22 incorporated herein by reference thereto. The
23 function of isolating collar 200 is conventionally to
24 electrically isolate at least a portion of the
25 pipeline, wherein electrical power is applied to the
26 pipeline or tubing string to facilitate heating of
27 the pipeline or tubing string. Heating of the
28 pipeline or tubing string is to prevent the formation
29 of solids, particularly for use with pipelines or
30 tubing strings containing paraffin.

31

1 Isolating collar 200 is provided with threads 204 at
2 an upper end of an inner connector 202. Threads 204
3 facilitate connection of the isolating collar 200 to
4 a tubing string or the like thereabove. Inner
5 connector 202 is substantially tubular and is
6 typically of a steel construction with material to
7 suit the pipeline or tubing string to which it is
8 attached.

9
10 Inner connector 202 is provided with a continuous
11 screw thread 206 on an exterior surface for
12 engagement with an inner insulating seal sleeve 208.
13 Inner sleeve 208 is provided with a thread 210 that
14 allows it to be threadedly coupled to the thread 206
15 of the inner connector 202, and a thread 212 provided
16 on the interior of an outer connector 214. Inner
17 connector 202 is typically provided with sealing
18 means, such as O-rings 218, at a lower end thereof to
19 seal against sleeve 208.

20
21 Outer connector 214 is typically formed of
22 electrically conducting material such as steel, and
23 is concentrically attached to the inner connector 202
24 to be supported thereby. Outer connector 214 is
25 provided with an internal thread 216 at a distal end
26 thereof to facilitate connection of the isolating
27 collar 200 into a pipeline or tubing string attached
28 therebelow. The distal end of outer connector 214 is
29 also provided with sealing means, for example O-rings
30 220, on the inner bore thereof for sealing with the
31 sleeve 208.

1
2 An insulating material 222 is typically injected into
3 an annulus between the inner and outer connectors
4 202, 214 via a port 226. The insulating material 222
5 provides for electrical insulation between the inner
6 and outer connectors 202, 214, and can additionally
7 provide mechanical strength to support the weight of
8 the string below the collar 200. The insulating
9 material may be, for example, an epoxy such as
10 aromatic amine.

11
12 The insulating material 222 typically includes sleeve
13 208 that is typically formed of a plastic material.
14 Sleeve 208 bridges the space between the lower end of
15 the inner connector 202 and the seal means 220 and
16 prevents electrical contact between the inner and
17 outer connectors 202, 214 through water being
18 contained within the fluids flowing through the
19 collar 200.

20
21 Sleeve 208 and the first and second seals 218, 220
22 insulate between the inner and outer connectors 202,
23 214 and additionally prevent fluids from reaching the
24 insulating material 222 from the interior of the
25 isolating collar 200. The insulating material 222 is
26 preferably protected from contact with well fluids
27 that may cause a short circuit within the isolating
28 collar 200.

29
30 In certain embodiments of the isolating collar 200, a
31 nonsolid, noncompressible material is injected into

1 cavities in the lower end of the isolating collar
2 200. This material is confined under pressure so
3 that sleeve 208 is supported against internal
4 pressure. Thus, as pressure within the bore of the
5 isolating collar 200 increases, the pressure on the
6 nonsolid material increases and no substantial
7 pressure differential is created. The material is
8 preferably silicone. Before the nonsolid material is
9 injected, the area that it fills is typically
10 evacuated.

11
12 Isolating collar 200 is based on an oilfield thread
13 for coupling but can be adapted to other pipe
14 coupling threads and indeed flange couplings without
15 compromising or altering the core design of the
16 collar. Thus, those skilled in the art will
17 appreciate that isolating collar 200 can be coupled
18 to the pipeline or tubing string in any conventional
19 manner, depending upon the particular application
20 and/or the structure of the pipeline or tubing
21 string.

22
23 Isolating collar 200 includes a ring 228 that allows
24 external electrical power and transmissions to be
25 coupled to the outer connector 214. Ring 228 is
26 provided with internal threads 230 that engage
27 external threads 232 on an upper end of the outer
28 connector 214. A blind conduit 234 is provided on
29 the ring 228 to allow for connection of electrical
30 signals using any conventional means. Thus,
31 electrical signals, such as power and/or

1 communications, may be transmitted via the outer
2 connector 214 to any receiver that is electrically
3 coupled to the pipeline or tubing string suspended
4 below the isolating collar 200.

5
6 Fig. 5 shows an alternative embodiment of an
7 isolating collar 300. Collar 300 is substantially
8 the same as collar 200. Isolating collar 300 is
9 described in US Patent Nos 4,861,074 and 4,716,960
10 assigned to Production Technologies Inc, the entire
11 disclosure of these patents being incorporated herein
12 by reference thereto.

13
14 Isolating collar 300 includes an upper connector 302
15 and a lower connector 304. The upper and lower
16 connectors 302, 304 are threadedly coupled using
17 threads 306 on the upper connector 302 and threads
18 308 on the lower connector 304. It should be noted
19 that the upper and lower connectors 302, 304 may be
20 coupled in any conventional manner.

21
22 The cavity between the threads 306, 308 is preferably
23 filled with an insulating material 310 as in the
24 previous embodiment, the material 310 typically being
25 epoxy. The insulating material 310 typically
26 provides for electrical insulation between the two
27 connectors 302, 304, and the interlocking threads
28 306, 308 give mechanical support to allow a tubing
29 string to be suspended from the lower connector 304.

30

1 The lower connector 304 is provided with a threaded
2 bore 312 for receiving an electrical conduit 314.

3

4 The upper and lower connectors 302, 304 are provided
5 with a central bore 302b, 304b respectively, to allow
6 the passage of fluids through the collar 300, and
7 also threads 302t, 304t respectively, to allow the
8 collar 300 to be coupled into a tubing string or
9 pipeline.

10

11 The upper connector 302 is provided with a
12 counterbore 316 that receives the electrical conduit
13 314. The counterbore 316 is typically filled with
14 epoxy insulating material when the electrical conduit
15 314 is in place.

16

17 Electrical conduit 314 typically comprises a metal
18 rod having a lower threaded end 314l for threadedly
19 engaging threaded bore 312 in the lower connector 304
20 to facilitate electrical connection. The conduit 314
21 has an enlarged diameter portion 314e to reduce the
22 electrical resistance of the conduit 314 in the area
23 of the enlarged portion 314e, so that the insulating
24 material in this area is not overheated when high
25 power signals are transmitted.

26

27 The electrical conduit 314 is provided with an
28 electrical connector 318 at its upper end, the
29 connector 318 being attached by any suitable means,
30 such as a screw thread. The connector 318 is
31 provided with a blind internal bore 320 to which

1 electrical connection may be made, for example by
2 soldering. The connector 318 is typically
3 electrically insulated by using a rubber boot, for
4 example, positioned over the connector 318.

5
6 Thus, both isolating collars 200, 300 facilitate
7 electrical isolation of the pipeline above the
8 collars 200, 300 but allow transmission of electrical
9 signals on the pipeline suspended below the collars
10 200, 300.

11
12 In addition to the use of the isolating collar 200,
13 300 the pipeline system 100 (Fig. 1) is preferably
14 isolated from electrical ground between the collars
15 200a, 200b to maintain the isolation. This requires
16 the pipeline to have a degree of insulation or be
17 spaced off any grounded objects, by insulating mounts
18 or protectors, as will be described hereinafter.

19
20 It will be appreciated that the pipeline 100 is
21 required to be isolated to some extent from ground.

22
23 Referring now to Fig. 9, there is shown an oilwell,
24 generally designated 400, with tubular casing 412 and
25 a pipe based production tubing. The oilwell
26 generally includes a well head 402 that may be of any
27 conventional type, that has a tubing string suspended
28 therebelow. The tubing string typically comprises a
29 plurality of tubulars 404 that are coupled together
30 in a known manner (such as by threaded couplings). A
31 number of isolating collars 200a, 200b, 200c are

1 coupled into the tubular string at specified
2 locations, to electrically isolate the tubular
3 string. The isolating collars 200 may comprise the
4 isolating collars 300.

5
6 The master unit 10 can be either directly or
7 capacitively coupled to the single wire connection to
8 the downhole system, via the isolating collar 200a.
9 Power and data transmissions to and from the master
10 unit 10 are driven between the single live contact
11 through a wellhead penetrator 406 provided in the
12 wellhead 402. The wellhead penetrator 406 would be
13 the type of penetrator used for electrical
14 submersible pump (ESP) installations or permanent
15 gauge installations. Fig. 10 shows a typical
16 penetrator 406, although any proprietary well head
17 penetration device with suitable pressure and
18 electrical rating may be used.

19
20 Referring now to Figs 10a and 10b, the function of a
21 wellhead penetrator 406 is to allow electrical cables
22 to be fed through an oil field wellhead 402. The
23 wellhead 402 forms a pressure cap on the well and so
24 any electrical penetration has to maintain the
25 pressure seal of the wellhead 402.

26
27 Fig 10a illustrates an API flange unit, and Fig. 10b
28 illustrates an NPT mounted unit, but both units
29 perform the same function and are substantially the
30 same. The penetrators 406 include a primary pressure
31 seal 450 that typically comprises a metal-to-metal

1 seal. Seal 450 couples the body of the penetrator
2 406 to the wellhead (schematically shown in Figs 10a
3 and 10b as 452) itself. A seal 454 seals against a
4 cable running through the wellhead 452 itself, seal
5 454 typically being a metal-to-metal seal.

6

7 A glass-to-metal electrical penetrator allows
8 electrical inner conductors to pass through a
9 pressure-tight barrier 456.

10

11 The penetrator 406 includes a connector 458 to
12 facilitate coupling of an external cable onto the
13 wellhead penetrator 406. Connector 458 may comprise
14 a gland or any other type of cable exit.

15

16 The penetrator 406 may be mounted to the wellhead 452
17 using any conventional means, such as bolts 460 (Fig.
18 10a) or a screw thread 462 (Fig. 10b). The wellhead
19 protector 406 typically includes a pressure-tight
20 steel body 464 that houses and generally mounts the
21 major components of the penetrator 406.

22

23 The single wire from the base of the penetrator 406
24 is fed on to the isolating tubing collar 200a mounted
25 below the wellhead 402 and a tubing hanger 408 (Fig.
26 9). Electrical contact between the single wire of
27 the wellhead penetrator 406 and the isolated portion
28 of the tubing below the isolating collar 200a can be
29 achieved by using either of the isolated collars 200,
30 300 described herein, or otherwise.

31

1 Alternatively, the single wire of the wellhead
2 penetrator 406 can be coupled directly to any part of
3 the isolated tubing string using a simple tubing
4 based connection as shown in Fig. 11. Fig. 11
5 schematically illustrates the wellhead penetrator 406
6 and two methods of coupling the wire from the
7 penetrator 406 to the isolated portion of tubing.
8 The first method is described above, wherein the
9 isolating collar 200a is used to transmit electrical
10 signals from the wellhead penetrator 406 to the
11 isolated portion of the tubing string.

12
13 Alternatively, the wire from the wellhead penetrator
14 406 may be coupled to the isolated pipeline using a
15 cable coupling (not shown) that is coupled to a
16 tubing clamp 410.

17
18 Referring again to Fig. 9, the tubing string is
19 prevented from touching casing 412 of the oilwell 400
20 by insulated protectors 414. The insulated
21 protectors 414 can be mounted at either couplings 416
22 between successive tubulars 404 or at a mid point 418
23 in the length of a tubular 404. The insulated
24 protectors 414 are typically of a rubber or plastic
25 construction and are commonly used in the oil and gas
26 industry. They are generally two types of protectors
27 414, either protecting across the tubing joint (cross
28 coupling protectors) such as at coupling 416 or
29 clamping at any point in the pipe (mid joint
30 protectors) such as at mid point 418.

31

1 The slave units 50 are typically mounted to the
2 production tubing 404. In this example, two slave
3 units 50a, 50b are shown. Fig. 9a shows an enlarged
4 view of a section of the tubing of Fig. 9
5 illustrating how the slave units 50a, 50b are coupled
6 to the tubing string. Slave units 50a have a carrier
7 or mandrel 420 that attaches the slave unit 50a to
8 the tubing 404, a slave module 422 that contains the
9 electronic circuitry described above, and an
10 electrical return path that typically comprises the
11 casing 424 of the slave unit 50a. Casing 424
12 typically comprises a spring contact.

13
14 The slave unit 50a is further illustrated in Fig. 12.
15 The slave unit 50a is electrically connected to the
16 tubing 404 by clamping the electronic module 422
17 containing the circuitry onto the tubing based
18 mandrel 420. Mandrel 420 may be machined from solid
19 steel, fabricated or a combination of solid machining
20 and bolted clamps. The general structure of the
21 mandrel 420 is of steel to suit the rest of the
22 tubing string. The electronics of the slave unit 50a
23 are isolated from a protective pressure housing 426,
24 housing 426 being conventionally grounded, but being
25 live in this particular embodiment. The electronic
26 module 422 mounted to the mandrel 420 has insulated
27 end pieces 428 that the spring contact 424 is mounted
28 to. This electrically isolates the spring loaded
29 contacts 424 from both the mandrel 420 and the body
30 of the electronic module 422. The slave unit
31 pressure housing 426 typically supports the spring

1 contact 424 and also maintains pressure integrity
2 during wiping action of the spring contact 424.

3
4 Thus, the electronics in the electronics module 422
5 is coupled between the live pipe or tubing 404 and
6 the ground potential casing 412 (not shown in Fig.
7 12), thus drawing power from the live tubing 404.

8
9 The simplest return path connection is a
10 spring-loaded wiper arm 424 (Fig. 12), that pushes
11 against the casing 412 of the well 400. The
12 electrical return contact can be a hydraulically
13 operated latching arm (not shown) or alternatively,
14 may comprise the grips of a hydraulically set packer
15 (not shown).

16
17 Thus, the slave units 50 are electrically coupled to
18 the master unit 10 using only the production tubing
19 404 and can monitor sensors and control actuators
20 (not shown) as described above.

21
22 Furthermore, the telemetry system can be used in a
23 multi-lateral well (several branches downhole from a
24 single borehole) and slave units 50 can be installed
25 in each of the multiple branches (not shown). Thus,
26 the system may operate with multiple slave units 50
27 in various branches of the well, with all of the
28 slave units 50 acting in parallel on the same system,
29 and with no requirement for any splicing or joint in
30 the system other than a union on the tubing system
31 404 that is inherent for the well to function.

1

2 Referring again to Fig. 9, the system is shown as
3 having multiple slaves 50a, 50b, 50c coupled to the
4 production tubing 404 at any convenient locations.
5 The slave units 50a, 50b, 50c may be positioned to
6 allow for the control, operation and interrogation of
7 a plurality of different instruments, sensors or load
8 actuators as required.

9

10 Where a slave unit 50 requires to be mounted below a
11 packer or valve 430 (which cannot be isolated
12 electrically from the casing 404) an isolating tubing
13 collar 200b will be mounted above the packer or valve
14 430, and a further isolating collar 200c mounted
15 below the packer or valve 430. A cable 432 is used
16 to circumvent the packer or valve 430 (or any other
17 obstructing object) using a standard isolated packer
18 penetrator 434.

19

20 The slave units 50a, 50b, 50c in this embodiment may
21 be used for reservoir monitoring using pressure
22 and/or temperature sensors, flow meters, and fluid
23 temperature probes. These slave units 50a, 50b, 50c
24 may also be used to operate and control gas lift
25 valves, fluid production intake valves and fluid
26 circulating valves. The slave units 50a, 50b, 50c
27 may also be used to control a packer with a flow
28 through valve controlled from the master unit 10.
29 The telemetry system has the capability to apply
30 substantial electrical power to downhole actuators
31 (not shown) due to the low resistance of the pipe 404

1 in the tubing string. Thus, the telemetry system can
2 be implemented to drive and control large motors,
3 actuators and the like.

4
5 In some downhole applications, fluid in the space
6 between the casing 412 and the outside surface of the
7 production tubing 404 is conductive. In this case,
8 the tubing 404 in addition to being spaced from the
9 casing 412 by the insulating protectors 424, would
10 also be coated with an insulating paint or the like
11 to increase the amount of electrical isolation
12 between the tubing 404 and casing 412.

13
14 The telemetry system can tolerate a certain degree of
15 leakage current from the tubing 404 to the casing 412
16 so that complete coating and full isolation is not a
17 primary requirement. The leakage tolerance is
18 achieved by using telemetry signal levels that have
19 sufficient margin to tolerate this leakage current.

20
21 Referring now to Figs 13a and 13b, Fig. 13a shows a
22 subsea pipeline system 500, that includes a dual
23 pipeline 502, 504, and Fig. 13b illustrates a subsea
24 pipeline system 550 that includes a single pipeline
25 552. In Figs 13a and 13b, the pipelines 502, 504,
26 552 are typically under water (either fresh or sea
27 water) and the pipelines 502, 504, 552 are used as
28 the power and communications transmission medium for
29 the telemetry system.

30

1 The master unit 10 of the telemetry system includes a
2 power supply and master control unit, and is
3 typically located above the water level and before
4 the point where the pipeline 502, 504, 552 enters the
5 water. The pipelines 502, 504, 552 generally do not
6 have any other power source present on the pipelines
7 502, 504, 552 in such applications, and thus it is
8 not necessary to capacitively couple the master unit
9 10 to the pipeline 502, 504, 552. Thus, direct
10 coupling of the ac power from the master unit 10 to
11 the pipelines 502, 504, 552 may be used. However, it
12 will be appreciated that capacitive coupling will be
13 required where the pipelines 502, 504, 552 are used
14 to carry any other power source.

15
16 A single or two wire connection is made from the
17 master unit 10 to a connection point 504 at or near
18 the isolating collar 200a. At the connection point
19 504, the live power wire from the master unit 10 is
20 coupled to an isolated portion 502i of the pipeline
21 502, by making connection to the metallic body of the
22 isolated portion 502i of the pipeline 502. The
23 electrical contact can be made by clamping to the
24 pipeline 502, or using a modified portion of pipe
25 with an electrical connector or coupling fitted
26 thereto, or in any other suitable manner. An
27 isolating tubing collar 200a in the pipeline 502
28 electrically isolates the pipeline 502 from a source
29 506 of the transported fluid, and supports the weight
30 or tension in the pipeline 502. A second isolating
31 collar 200b is positioned at or near a delivery end

1 502d of the pipeline 502. The isolating collars
2 200a, 200b can be either of an oil field thread type,
3 or may be coupled to the pipeline 502 at the
4 termination of the dual pipe couplings, where the
5 couplings may be modified to suit the pipeline
6 material and coupling method, but the internal
7 structure of the collars 200a, 200b is as described
8 above. It should be noted that either of the
9 isolating collars 200, 300 may be used.

10

11 In this way, a transmission zone 502z is defined
12 between the isolating collars 200a, 200b. The master
13 unit 10 is electrically coupled to the transmission
14 zone 502z using the isolating collar 200a, for
15 example, as described above. Slave units 50a, 50b
16 can then be electrically coupled at any point within
17 the transmission zone 502z so that any power and/or
18 data transmissions from the master unit 10 (or data
19 transmissions from the slave units 50a, 50b to the
20 master unit 10) can be retrieved.

21

22 The isolated portion 502i of the pipeline 502 is
23 insulated partially from the water by both coating of
24 the pipeline 502 and insulating protectors 510. The
25 coating can be selected from any of a number of
26 available techniques. The insulating coatings
27 typically provide a substantial fluid resistance, and
28 complete water sealing is preferable but not
29 essential. Similarly, at pipe joints under water in
30 the pipeline 502, the joints should be covered with
31 plastic or rubber insulating covers to provide

1 protection against physical damage, any electrical
2 shorting and also water ingress into the joints.
3 Injection of insulating grease or sealant into the
4 joint covers is again preferable but not necessary.

5
6 At any point in the transmission zone 502z, slave
7 units 50a, 50b can be attached to provide monitoring
8 of sensors or control of actuators as described
9 above. Any number of slave units 50 may be coupled
10 into the system as required.

11
12 Referring to Fig. 14, the slave units 50a, 50b are
13 typically mounted so that the units 50a, 50b make
14 electrical contact with the live metal of the
15 transmission zone 502z. If the body of the
16 protective pressure housing 426 (Fig. 14) is attached
17 to the metal of the pipe 502, 504, 552 then it will
18 be live and will require an isolated ground contact
19 that is connected to the local ground 554 (Fig. 13b)
20 or second pipeline 504 (Fig. 13a) that are used as
21 ground returns. The ground contact is typically made
22 by attaching a fly lead 436 to one of the insulated
23 end pieces 428, and thus end pieces 428 are typically
24 grounded. The protective pressure housing 426
25 typically protects the electronics from the water
26 pressure, and additionally isolates the ground
27 contact from the live pipe 502, 504, 552.

28
29 The slave units 50 require a ground or earth to
30 complete the electrical circuit. This can be
31 achieved using local grounding 554 such as the

1 seabed, a lake bed or the like, schematically
2 illustrated in Fig. 13b. Alternatively, this may
3 also be achieved by using another pipeline 504
4 running next to the "live" one as the ground return,
5 schematically illustrated in Fig. 13a.

6
7 The slave unit 50 located underwater can have several
8 functions including strain gauge measurement on
9 pipeline stress, lifting forces from riser buoyancy
10 elements, fluid temperature measurement, flow rate
11 measurement in co-mingled lines, or the like.
12 Further uses could be to provide control of a subsea
13 installed wellheads using the underwater pipeline as
14 the only power and communications medium. The
15 functionality of the slave unit 50 could include the
16 control of wellhead actuators, measurement of choke
17 positions and measurement of local pressure and
18 temperatures.

19
20 A further use of this system would include coupling
21 an underwater acoustic modem to the slave unit 50 to
22 allow interrogation of long pipeline sensor systems
23 from floating rigs, FPSO and ships while working on
24 the pipe line 502, 504, 552 or associated systems.

25
26 Referring now to Figs 15a and 15b, there is shown a
27 dual and single pipeline system 600, 650
28 respectively, that are typically located on the
29 surface. The master unit 10 includes a power supply
30 and master control unit and is typically located near
31 the source 610 of the pipeline 602, 604, 650, or

1 coupled to the pipeline 602, 604, 652 using a
2 suitable cable. An isolating tubing collar 200a is
3 coupled into the pipeline 602, 652 to isolate the
4 pipe 602, 652 from the source 606 of the transported
5 fluid, and support the pipeline 602, 652. In
6 addition, there is a second isolating collar 200b
7 positioned at the delivery end 602d, 652d of the
8 pipeline 602, 652. Either isolating collar 200 or
9 collar 300 may be used.

10

11 The live or power line from the master unit 10 is
12 coupled to an isolated section 602i, 652i of the
13 pipeline 602, 652 using a clamp or connector to
14 attach to the steel of the pipeline 602, 652, similar
15 to the embodiments shown in Figs 13a and 13b. The
16 isolated section 602i, 652i of the pipeline 602, 652
17 is insulated partially from the weather and/or the
18 surrounding surface by both coating of the pipeline
19 602, 652 and insulating protectors 610. The coating
20 and insulating joint protectors 610 typically provide
21 a substantially water-tight cover. It is not a
22 requirement that the coating and protectors 610 are
23 completely water-tight.

24

25 In this way, a transmission zone 602z is defined
26 between the isolating collars 200a, 200b. The master
27 unit 10 is electrically coupled to the transmission
28 zone 602z using the isolating collar 200a, for
29 example, as described above. Slave units 50a, 50b
30 can then be electrically coupled at any point within
31 the transmission zone 602z so that any power and/or

1 data transmissions from the master unit 10 (or data
2 transmissions from the slave units 50a, 50b to the
3 master unit 10) can be retrieved
4

5 Where the pipeline 602, 652 is on the surface, the
6 pipeline 602, 652 is supported along its length by
7 insulating supports (not shown) to prevent it from
8 grounding to earth. These supports are typically
9 fabricated from standard supports with isolating
10 rings to space the mounting from the pipeline 602,
11 652.
12

13 As before, a slave unit 50 can be coupled to the
14 transmission zone 602z, 652z at any point along its
15 length, and multiple slave units 50 may be used.

16 Slave units 50a, 50b can be coupled to the
17 transmission zone 602z, 652z to provide monitoring of
18 sensors or control of actuators, as described above.
19

20 Referring now to Fig. 16, the slave units 50a, 50b
21 would typically be mounted on a grounded structure
22 (not shown) around the pipeline 602, 652 and a single
23 wire 620 run to a clamp 622 or connector connecting
24 the slave unit 50a, 50b live connect to the metal of
25 the pipeline 602, 652.
26

27 The slave units 50 require a ground or earth to
28 complete the electrical circuit. This can be
29 achieved by either using local grounding 624 like the
30 earth (schematically illustrated in Figs 15b and 16),
31 or may also be achieved by using another pipeline 604

1 running next to the "live" one as the ground return
2 (as illustrated in Figs 15a and 16).
3

4 The slave unit 50 can perform a plurality of
5 functions in relation to a surface pipeline 602, 652,
6 such as fluid flow measurement, valve control, pipe
7 corrosion or strain measurement, fluid composition
8 measurement, pressure, temperature, vibration and
9 also pipe inclination for subsidence monitoring.
10 Shut down valves could also be driven from a slave
11 unit 50 as well as control of pumps and drain or
12 bleed valves to control fluid pumping or control
13 equipment remotely using the pipeline 602, 652 as the
14 control link.
15

16 This particular embodiment is useful for controlling
17 remote pumping stations where the station is far
18 removed from electrical power and/or telephone lines.
19 The telemetry system can provide both power to the
20 pumps, and also the ability to measure and control
21 the pumping operation.
22

23 Fig. 17 illustrates a surface pipeline comprising
24 first and second isolated pipelines 702, 704 (similar
25 to the system shown in Figs 13a, 13b), and an
26 isolated subsea or downhole tubing 706 (similar to
27 the system shown in Fig. 9). An oilwell 708 which
28 has a wellhead 712 on the surface has the isolated
29 pipelines 702, 704 coupled thereto from the surface,
30 and on the same system has the isolated downhole
31 production tubing 706 suspended therebelow.

1
2 The pipeline 702 from the surface is isolated with an
3 isolating tubing collar 200a at the surface, and a
4 second isolating collar 200b is provided at or near
5 the wellhead 712, creating a transmission zone
6 therebetween. An electrical link 714 couples the
7 power and data transmissions from the isolated supply
8 from the surface pipeline 702 to a wellhead
9 penetrator 716 and this in turn couples the power and
10 data transmissions to the isolated downhole tubing
11 706. The downhole tubing 706 typically has at least
12 one slave unit 50 coupled thereto (Fig. 17 shows two
13 slave units 50a, 50b) that are connected back to
14 electrical ground through the downhole casing 718.
15 As before, slave units 50c and 50d can be coupled
16 anywhere in the isolated transmission zone of the
17 surface pipeline 702, or the downhole tubing 706.
18 The slave units 50c, 50d may use the second pipeline
19 704 as a ground return, or may be grounded locally,
20 depending upon the application and/or the location of
21 the slave units 50c, 50d.

22
23 A further extension of this system would be to use a
24 single subsea pipeline (not shown) to couple several
25 downhole wells together on the same system. This
26 would also apply where the oilwell had multi-lateral
27 bore holes and each arm of the multi-lateral system
28 was both isolated and connected to the same power
29 source. The system would have the ability to supply
30 substantial levels of power to drive the electronics

1 and controls at each of the wells that are coupled to
2 the slave units 50.

3

4 Thus, there is provided a telemetry system that in
5 certain embodiments allows for both power and data
6 transmissions across an isolated tubing string or
7 pipeline. The system in certain embodiments uses
8 frequency-shift keying (FSK) and pulse-width
9 modulation to allow for the transmission of data
10 across the pipeline or tubing string.

11

12 The system in certain embodiments is flexible in that
13 it allows for a number of slave units to be located
14 remotely from one or more master units, the master
15 units being used to control the operation of the
16 slave units. The slave and master units are
17 typically coupled to a single transmission medium,
18 such as the isolated pipeline or tubing string. The
19 system in certain embodiments can also support the
20 use of more than one master unit to control the slave
21 units from more than one point within the system.

22

23 There is also provided a method of transmitting
24 pulse-width modulated power over an isolated pipeline
25 or tubing string and recovering this as both power
26 and data. There is also provided a method of
27 transmitting frequency-shifted data that is
28 synchronised to a received power waveform.

29

- 1 Modifications and improvements may be made to the
- 2 foregoing, without departing from the scope of the
- 3 present invention.

1 **CLAIMS**

2 1. A telemetry system comprising a master unit, and
3 at least one slave unit remote from the master unit,
4 the master and slave units communicating via a
5 transmission system, wherein the telemetry system is
6 capable of transmitting power and data transmissions
7 between the units, and wherein the transmission
8 system includes an at least partially isolated tubing
9 string or pipeline.

10

11 2. A telemetry system according to claim 1, wherein
12 the pipeline or tubing string is electrically
13 isolated using at least one isolating collar.

14

15 3. A telemetry system according to claim 2, wherein
16 the isolating collar comprises first and second
17 connectors, the first and second connectors being
18 threadedly coupled together.

19

20 4. A telemetry system according to claim 3, wherein
21 an electrical isolating material is injected between
22 the first and second connectors to isolate the
23 connectors from one another.

24

25 5. A telemetry system according to claim 3 or claim
26 4, wherein the isolating collar includes means for
27 conveying electrical signals from outwith the collar
28 to the second connector.

29

30 6. A telemetry system according to any preceding
31 claim, wherein the pipeline or tubing string is

1 coated with an electrically isolating coating to at
2 least partially isolate the pipeline or tubing
3 string.

4
5 7. A telemetry system according to any preceding
6 claim, wherein the at least partially isolated
7 pipeline or tubing string comprises a surface
8 pipeline or tubing string.

9
10 8. A telemetry system according to any one of
11 claims 1 to 7, wherein the at least partially
12 isolated pipeline or tubing string comprises a subsea
13 pipeline or tubing string, or a downhole pipeline or
14 tubing string.

15
16 9. A telemetry system according to any preceding
17 claim, wherein the at least partially isolated
18 pipeline or tubing string comprises any combination
19 of surface, subsea or downhole pipelines or tubing
20 strings.

21
22 10. A telemetry system according to any preceding
23 claim, wherein the pipeline or tubing string includes
24 a first isolating collar at or near a source of fluid
25 flowing within the pipeline or tubing string.

26
27 11. A telemetry system according to claim 10,
28 wherein the pipeline or tubing string includes a
29 second isolating collar at or near a sink for the
30 fluid in the pipeline or tubing string.

31

1 12. A telemetry system according to claim 10 or
2 claim 11, wherein the master unit is electrically
3 coupled to the pipeline or tubing string via the
4 first isolating collar.

5
6 13. A telemetry system according to any preceding
7 claim, wherein at least one slave unit is coupled to
8 the pipeline or tubing string.

9
10 14. A telemetry system according to any preceding
11 claim, wherein the slave unit comprises a mandrel, a
12 slave module, and an electrical return path.

13
14 15. A telemetry system according to claim 14,
15 wherein the mandrel facilitates attachment of the
16 slave unit to the pipeline or tubing string.

17
18 16. A telemetry system according to claim 14 or claim
19 15, wherein the mandrel facilitates transmission of
20 the electrical power and data transmissions from the
21 pipeline or tubing string to the electronics of the
22 slave unit.

23
24 17. A telemetry system according to any one of
25 claims 14 to 16, wherein the slave module houses the
26 electronics of the slave unit.

27
28 18. A telemetry system according to any one of
29 claims 14 to 17, wherein the electrical return path
30 comprises a spring contact for engaging an earth
31 point.

1

2 19. A telemetry system according to claim 18,
3 wherein the earth point is a local earth, a further
4 tubular such as a second pipeline, a subsea or
5 surface casing, or a casing of a downhole well.

6

7 20. A telemetry system according to any preceding
8 claim, wherein pulse-width modulation is used to
9 facilitate data transmission from the master unit to
10 the slave unit.

11

12 21. A telemetry system according to claim 20,
13 wherein the power transmission is modulated with the
14 data transmission using pulse-width modulation.

15

16 22. A telemetry system according to any preceding
17 claim, wherein frequency-shift keying (FSK) is used
18 to facilitate data transmission from the slave unit
19 to the master unit.

20

21 23. A telemetry system according to claim 22,
22 wherein the FSK frequencies are superimposed on a
23 carrier frequency.

24

25 24. A telemetry system according to claim 23,
26 wherein the carrier frequency is the same frequency
27 as the power transmission frequency.

28

29 25. A telemetry system according to any one of
30 claims 22 to 24, wherein the data transmission is

1 synchronised to the "high" cycle of the power
2 transmission.

3

4 26. A telemetry system according to any one of
5 claims 22 to 25, wherein the data transmission is
6 synchronised to the "low" cycle of the power
7 transmission.

8

9 27. A telemetry system according to any one of
10 claims 22 to 26, wherein the data transmission is
11 synchronised to both the high and the low cycles of
12 the power transmission.

13

14 28. A telemetry system according to any preceding
15 claim, wherein more than one slave unit is used.

16

17 29. A telemetry system according to claim 28,
18 wherein the data transmission from the master unit to
19 the slave unit includes an address of the slave unit.

20

21 30. A telemetry system according to claim 29,
22 wherein the data transmissions include data error
23 detection and/or correction.

24

25 31. A telemetry system according to claim 30,
26 wherein the data error detection and/or correction
27 comprises a Hamming code.

28

29 32. A telemetry system according to any preceding
30 claim, wherein the master unit comprises a processor
31 to control the operation of the master unit; a power

1 waveform generator; and signal recovery and
2 conditioning circuitry.

3

4 33. A telemetry system according to claim 32,
5 wherein the processor applies pulse-width modulation
6 to the power transmission when data transmission is
7 required from the master unit to the slave unit.

8

9 34. A telemetry system according to claim 32 or
10 claim 33, wherein when not transmitting data, the
11 processor defaults the power transmission to a 50%
12 duty cycle.

13

14 35. A telemetry system according to any one of
15 claims 32 to 34, wherein the signal recovery and
16 conditioning circuitry allows data transmitted by the
17 at least one slave unit to be extracted and recovered
18 from the transmission system.

19

20 36. A telemetry system according to any preceding
21 claim, wherein the slave unit comprises a processor
22 to control the operation of the slave unit;
23 rectifying and regulating circuitry in a first
24 channel; recovery and conditioning circuitry in a
25 second channel; and frequency generating and mixing
26 means.

27

28 37. A telemetry system according to claim 36,
29 wherein the frequency mixing and generating means
30 typically comprises a frequency-shift keying (FSK)
31 generator; an FSK mixer; and a line driver.

1
2 38. A method of transmitting power and data from a
3 master unit to at least one slave unit remote from
4 the master unit, the master and slave units
5 communicating via a transmission system, the
6 transmission system including an at least partially
7 isolated pipeline or tubing string, the method
8 comprising the steps of

9 generating a power transmission at the master
10 unit;

11 generating a data transmission and synchronising
12 the data transmission with the power
13 transmission at the master unit;

14 transmitting the power and data transmissions
15 via the transmission system to the slave unit;
16 and

17 recovering the power and data transmissions at
18 the slave unit.
19

20 39. A method of transmitting data to a master unit
21 from at least one slave unit remote from the master
22 unit, the master and slave units communicating via a
23 transmission system, the transmission system
24 including an at least partially isolated tubing
25 string or pipeline, the method comprising the steps
26 of

27 generating a power transmission at the master
28 unit and transmitting the power transmission to
29 the slave unit;

30 recovering the power transmission at the slave
31 unit;

1 generating a data transmission at the slave unit
2 and synchronising the data transmission with the
3 power transmission;
4 transmitting the data transmission via the
5 transmission system to the master unit; and
6 recovering the data transmission at the master
7 unit.

8

9 40. A method according to either claim 38 or claim
10 39, wherein the method includes the further steps of
11 dividing the data transmission into a series of
12 sub-windows;
13 transmitting a specified data transmission from
14 the slave unit to the master unit;
15 receiving the specified data transmission at the
16 master unit;
17 determining which of the sub-windows reliably
18 transmitted the specified data transmission.

19

20 41. A method according to claim 40, wherein the sub-
21 windows that did not reliably transmit data are
22 filtered out or ignored for subsequent transmissions.

23

24 42. A method of receiving and converting power and
25 data transmissions sent from a master unit to at
26 least one slave unit remote from the master unit, the
27 master and slave units communicating via a
28 transmission system, the transmission system
29 including an at least partially isolated pipeline or
30 tubing string, the method comprising the steps of

1 receiving a power transmission at the slave
2 unit;
3 dividing the power transmission into two
4 channels;
5 rectifying and regulating the power transmission
6 in a first channel; and
7 recovering the data transmission in a second
8 channel.

9
10 43. A method of receiving data transmitted by a
11 master unit from at least one slave unit remote from
12 the master unit, the master and slave units
13 communicating via a transmission system, the
14 transmission system including an at least partially
15 isolated pipeline or tubing string, the method
16 comprising the steps of
17 receiving the data transmission at the master
18 unit;
19 filtering and conditioning the data
20 transmission; and
21 regenerating the transmitted data.

22
23 44. A method according to either claim 42 or claim
24 43, wherein the method includes the further steps of
25 dividing the data transmission into a series of
26 sub-windows;
27 transmitting a specified data transmission from
28 the slave unit to the master unit;
29 receiving the specified data transmission at the
30 master unit;

1 determining which of the sub-windows reliably
2 transmitted the specified data transmission.

3

4 45. A method according to claim 44, wherein the sub-
5 windows that did not reliably transmit data are
6 ignored or filtered out for subsequent transmissions.

7

8 46. A method according to any one of claims 38 to
9 45, wherein pulse-width modulation is used to
10 facilitate data transmission from the master unit to
11 the slave unit or vice versa.

12

13 47. A method according to claim 46, wherein the
14 power transmission is modulated with the data
15 transmission using pulse-width modulation.

16

17 48. A method according to any one of claims 38 to
18 47, wherein frequency-shift keying (FSK) is used to
19 facilitate data transmission from the slave unit to
20 the master unit or vice versa.

21

22 49. A method according to claim 48, wherein the FSK
23 frequencies are superimposed on a carrier frequency.

24

25 50. A method according to claim 49, wherein the
26 carrier frequency is the same frequency as the power
27 transmission frequency.

28

29 51. A method according to any one of claims 38 to
30 50, wherein the data transmission is synchronised to
31 the "high" cycle of the power transmission.

1

2 52. A method according to any one of claims 38 to
3 51, wherein the data transmission is synchronised to
4 the "low" cycle of the power transmission.

5

6 53. A method according to any one of claims 38 to
7 52, wherein the data transmission is synchronised to
8 both the low and high cycles of the power
9 transmission.

10

11 54. A method according to any one of claims 38 to
12 53, wherein the data transmissions include data error
13 detection and/or correction.

14

15 55. A method according to claim 54, wherein the data
16 error detection and/or correction comprises a Hamming
17 code, or other suitable technique.

18



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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4R (RTC,RTR,RTSR,RTSU,RTT); E1F (FHK)

Int Cl (Ed.7): H04B (3/54); E21B (47/12); G08C

Other: Online: EPODOC,WPI,JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X,P	GB 2338253 A (Schlumberger) see e.g. fig 4	1,6,8,9, 13,28
X,Y	GB 2180574 A (Camco) see especially page 2, lines 8-10	1,8,13
Y	GB 2083321 A (Marconi) see especially page 1, lines 115-127	28
Y	EP 0381802 A (Eastman Christensen) see especially fig 4 and col 13, lines 35-37	22
Y	US 4861074 A (Production Technologies) see fig 2	2-5,10,12
Y	US 4716960 A (Production Technologies) see fig 3	2-5,10,12

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